DOCUMENT RESUME

ED 155 005 SE 024 230

TITLE	Pump Operation Workshop.
INSTITUTION	Ontario Ministry of the Environment, Toronto.
PUB DATE	Sep 77
NOTE	157p.; For related documents, see SE 024 226-233; Not available in hard copy due to copyright restrictions; Contains colored pages which may not reproduce well
AVAILABLE FROM	Publications Centre, Ontario Ministry of Government Services, 880 Bay St., 5th Floor, Toronto, Ontario, Canada M7A 1N8 ($2.00; Orders must be accompanied by check or money order payable to "The Treasurer of Ontario")
EDRS PRICE	MF-$0.83 Plus Postage. HC Not Available from EDRS.
DESCRIPTORS	*Behavioral Objectives; *Environmental Education; Environmental Technicians; *Equipment Maintenance; Job Skills; Safety; Water Pollution Control; *Workshops
IDENTIFIERS	Ontario; Pumps

ABSTRACT

This manual was develcped for use at workshops designed as an extension of training for water and wastewater treatment personnel. The course consists of lecture-discussions and hands-on activities. Each of the lessons in this document has clearly stated behavioral objectives to tell the trainee what he should know or do after completing that topic. Areas covered in this manual include: pump system characteristics, types of pumps, pump controls, valves, motors, and safety. A glossary of terms is included for reference. (CS)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED155005

pump operation workshop

1977

U.S. DEPARTMENT OF HEALTH EDUCATION & WELFARE NATIONAL INSTITUTE OF EDUCATION

PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY

R. R. Doddridge

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) AND TO ORGANIZATIONS OPERATING UNDER AGREEMENTS WITH THE NATIONAL INSTITUTE OF EDUCATION. FURTHER REPRODUCTION OUTSIDE THE ERIC SYSTEM REQUIRES PERMISSION OF THE COPYRIGHT OWNER.

SE 024 230

Ministry of the Environment
Ontario

The Honourable George A. Kerr, Q.C., Minister

K.H. Sharpe, Deputy Minister

© *HER MAJESTY THE QUEEN IN RIGHT OF ONTARIO AS REPRESENTED BY THE MINISTER OF THE ENVIRONMENT, 1977*

PUMP OPERATION WORKSHOP

First edition September, 1977

Training & Certification Section
Personnel Services Branch
Ministry of the Environment
135 St. Clair Avenue West
Toronto, Ontario M4V 1P5

Other manuals relating to the water and wastewater treatment processes published by the Training and Certification Section, Ministry of the Environment, include:

Basic Gas Chlorination Workshop

Basic Water Treatment Operation

Basic Sewage Treatment Operation

Activated Sludge Process Workshop

Primary Treatment and Digestion Workshop

Preventive Maintenance Workshop

Surface Water Treatment Workshop

Copies may be purchased at:

Ontario Government Book Store
880 Bay Street
Toronto, Ontario

or may be ordered by Mail by writing to:

Ministry of Government Services
Publications Centre
3rd Basement Level
Macdonald Block, Queen's Park
Toronto, Ontario M7A 1N8

INTRODUCTION

The *Pump Operation Workshop* based on this manual covers five days. The workshop consists of lecture-discussions and hands-on training in the operation of pumps used in water and wastewater operations. It is an extension of training for water and wastewater treatment operation personnel.

For successful completion of the workshop, the trainee must achieve a passing grade of 70% in written and hands-on testing.

This manual was prepared jointly by the Ministry of the Environment and the Municipal Engineers Association of Ontario.

Training and Certification Section wishes to acknowledge the contributions and assistance of the:

MEA/MOE Course Sub-Committee

which was responsible for the development of the workshop and this manual.

Environmental Approvals Branch, MOE

Various manufacturers and suppliers of pumping equipment for the display models and illustrations.

TABLE OF CONTENTS

TOPIC	TITLE	PAGE
1	Characteristics of Material Pumped	
	Introduction	1-1
	Characteristics to be Considered	1-3
	Water Pumping	1-4
	Sewage Pumping	1-5
	Sludge Pumping	1-6
	Chemical Pumping	1-7
2	Pump System Characteristics	
	Basic Theory	
	General	2-1
	Capacity	2-2
	Pressure	2-2
	Vapour Pressure	2-4
	Suction Limitations	2-4
	Head	2-6
	NPSH	2-6
	System Head	
	Static Head	2-8
	Difference in Pressure	2-9
	Friction Head	2-10
	Entrance and Exit Losses	2-11
	Velocity Head	2-12
	System Head Curve	2-12
	Head Capacity Pump Curves	2-16
	Using the System Head Curve	2-17
	Parallel Operations	2-19

TOPIC	TITLE	PAGE
3	Types of Pumps	
	General	3-1
	Centrifugal Pumps	
	General	3-4
	Pump Components	3-7
	Impellers	3-9
	Pump Casings	3-11
	Wearing Rings	3-15
	Pump Shaft Bearings	3-15
	Propeller and Turbine Pumps	
	Axial Flow Pumps	3-17
	Mixed Flow Pumps	3-19
	Vertical Turbine Pumps	3-20
	Rotary (Positive Displacement) Pumps	
	General	3-22
	Types	3-23
	Relief Valves	3-26
	Summary of Features	3-27
	Reciprocating (Positive Displacement) Pumps	
	General	3-28
	Types	3-28
	Sizes and Size Designation	3-30
	Cylinder Liners	3-31
	Valve Arrangements	3-31
	Valve Types	3-32
	Length of Stroke	3-33
	Controlled Volume Pumps	3-33
	Piston Pumps vs. Plunger Pumps	3-35
	Applications	3-36

TOPIC	TITLE	PAGE
4	Pump Controls	
	General	4-1
	Pump Drives	
	Constant Speed Drives	4-2
	Variable Speed Drives	4-3
	Sensing Controls	
	Float Switches	4-4
	Bubbler Regulators	4-5
	Sonic Detectors and Capacitance Probes	4-5
	Pressure/Vacuum Switches	4-6
	Auxiliary Controls	
	Manual Controls	4-6
	Auxiliary Relays	4-7
	Time Delay Relays	4-7
	Overload Relays	4-7
	Time Controls	4-8
	Transducers	4-8
	Pump Motor Starters	
	General	4-8
	Full Voltage Starters	4-9
	Reduced Voltage Starters	4-9
	Wound Rotor Motor Starters	4-10
	Understanding Pump Controls	4-12
5	Valves	
	General	5-1
	Gate Valve	5-1
	Globe Valve	5-2

TOPIC	TITLE	PAGE
	Angle Valve	5-3
	Butterfly Valve	5-4
	Plug Valve	5-5
	Ball Valve	5-6
	Check Valve	5-7
	Pressure Relief Valve	5-9
	Needle Valve	5-10
	Sluice Gate & Shear Gate	5-10
	Solenoid Valve	5-11
6	Motors	
	Factors in Motor Selection	
	General	6-1
	Driving Power	6-1
	Speed of Rotation of Pump	6-2
	Environment	6-3
	Motor Types	
	Synchronous Motors	6-7
	Induction Motors	6-8
	Preventive Maintenance	6-9
7	Safety	
	Responsibility	7-1
	Hazards	7-2
	Personal Apparel and Working Conditions ..	7-2
	Hand Tools and Safety Practice	7-4
	Machine Guards	7-5
	Equipment Servicing	7-5

TOPIC	TITLE	PAGE
	Precautions for Electrical Maintenance ...	7-6
	Safety in Chemical Pumping	7-9
8	Practical Applications and Troubleshooting	
	(OBJECTIVES ONLY. Material to be issued during a workshop.)	
	Glossary	

LIST OF FIGURES

NUMBER	TITLE	PAGE
2-1	Static Heads - Suction Level Below Pump ℄	2-8
2-2	Static Heads - Suction Level Above Pump ℄	2-9
2-3	System Head Curve	2-12
2-4	System Head Curve (No Static Head)	2-13
2-5	Plotting a System Head Curve	2-15
2-6	Centrifugal Pump Characteristics Curves ..	2-16
2-7	Head Curve and Capacity Characteristic Curve	2-18
2-8	Use of Head Curve and Pump Capacity Curves in Pump Selection	2-18
2-9	Capacity Curve - Two Pumps in Parallel ...	2-20
2-10	Effect of Operating Pumps with Different Heads in Parallel	2-21
3-1	Centrifugal Pump & Direction of Fluid Flow	3-5
3-2	Single Stage End Suction Pump	3-6
3-3	Double Suction Pump	3-6
3-4	Typical Multi Stage Pump	3-7
3-5	Various Types of Impellers	3-10
3-6	Different Pump Casings	3-11
3-7	Double Volute Pump Casing	3-12
3-8	Solid-Case Pump	3-13
3-9	Split-Case Pump	3-13
3-10	Double Suction Pump Casing	3-14
3-11	Typical Pump to Motor Couplings	3-16
3-12	Typical Axial-Flow Propeller Pumps	3-18
3-13	Impeller for a Mixed-Flow Pump	3-19

NUMBER	TITLE	PAGE
3-14	Typical Vertical Turbine Pumps	3-21
3-15	Common Type Rotary Pumps	3-24
3-16(a)	Gear Type Rotary Pump with Internal Bearings	3-25
3-16(b)	Gear Type Rotary Pump with External Bearings	3-25
3-17	Typical Reciprocating Pumps	3-29
3-18	Diaphragm-Type Chemical Feed Pump	3-34
4-1	Control Logic Diagram Functions and Symbols	4-15
4-2	Schematic for Two Pumps and Float Switches	4-16
4-3	Typical Logic Diagram Two Pumps and Float Switches	4-17
4-4	Logic Diagram Travelling Water Screen	4-18
4-5	Typical Logic Diagram with Hydraulic Analogy	4-19
5-1	Cross-Section of Gate Valve	5-2
5-2	Cross-Section of Globe Valve	5-3
5-3	Cross-Section of an Angle Valve	5-4
5-4	Cross-Section of a Butterfly Valve	5-5
5-5	Cross-Section of a Plug Valve	5-6
5-6	Cross-Section of a Normal Ball Valve	5-7
5-7	Cross-Section of Typical Check Valves	5-8
5-8	Cross-Section of a Pressure Relief Valve	5-9
5-9	Cross-Section of a Needle Valve	5-10
5-10	Sluice Gate and a Shear Gate	5-11
5-11	Cross-Section of a Solenoid Valve	5-12
6-1	Characteristic Pump Curve	6-2

SUBJECT:

PUMP SELECTION

TOPIC: 1

CHARACTERISTICS OF MATERIALS PUMPED

OBJECTIVES:

The trainee will be able to:

1. **Describe the important characteristics of materials to be considered in pump selection.**

2. **Discuss the problems materials can create in**

   a) Water Pumping

   b) Sewage Pumping

   c) Sludge Pumping

   d) Chemical Pumping

3. **Recall the information on the**

   a) Pump

   b) Suction Side

   c) Discharge Side

   d) Drive

   that a supplier should be given to assist in pump selection.

4. **Define cavitation and describe its possible effects.**

CHARACTERISTICS OF MATERIALS PUMPED

INTRODUCTION

Pumps are subject to more misuse, abuse and faulty application than virtually any other type of equipment. In selecting a pump for a particular purpose or in replacing an installed pump which has failed either because of initial poor selection or because its task has changed, the operator usually disregards pump design and the type of service for which it is intended.

This Topic and Topic 2 will discuss the various factors involved in pump selection. These include

1. Material characteristics.
2. The system in which the pump is to be installed.

Manufacturers recognize the importance of these factors, and break their pump lines into types of service. Consequently, to obtain the proper pump for a specific job the supplier must be provided as much information as possible on the installation. *A rough sketch of the system is a most valuable aid.* The information he requires includes:

1. Material Data
   a) Type to be pumped.
   b) Viscosity of the material.
   c) Temperatures including maximum and minimum acceptable temperature.
   d) Specific Gravity.
   e) Weight per gallon.
   f) Corrosiveness and abrasiveness.
   g) Percentage solids and size of particles.

2. Pump Data

a) Capacity required.

b) Allowable variation.

c) Duty cycle including hours worked per day, week or month; continuous or intermittent operation.

d) Experience with previous pump (if applicable).

3. Suction Side Data

a) Is suction flooded?

b) Vertical, horizontal and total length of suction line.

c) Piping material.

d) Diameter of suction line.

e) Number of valves, tees and elbows in suction line.

f) List of any other equipment on suction side.

g) What is the pressure or vacuum?

h) What is variation in suction pressure?

4. Discharge Side Data

a) Back pressure at pump.

b) Pressure variation.

c) Vertical, horizontal and total length of discharge line.

d) Piping material and diameter.

e) Number of valves, tees and elbows in discharge line.

f) Additional equipment on discharge side of pump.

5. Drive Data

a) Electric motor or other drive furnished by plant or installer.

b) Horsepower, rpm, voltage, cycle, phase, AC or DC.

c) Motor type (open, splash-proof, totally enclosed, etc.)

d) Who supplies pump base, pump coupling?

This topic discusses the characteristics of materials to be pumped. Subsequent topics will discuss the pumping system and its components so that the information requirements can be determined.

CHARACTERISTICS TO BE CONSIDERED

The first consideration in any pump application problem must be given to the characteristics of the material that is to be pumped. These characteristics will, to a large extent, determine the *type of pump* selected as well as the design of the *piping system*.

A detailed listing of the characteristics of the material to be pumped is the first step in pump selection. The most important characteristics are:

1. The *chemical nature* of the material pumped. This includes such items as acidity or alkalinity, corrosive nature, crystallizing or polymerizing tendencies, dissolved oxygen concentration. It is a good idea to make note of any historic data acquired during previous handling of material.
2. The *viscosity*, (resistance to flow), of the material at pumping temperature and ambient temperature. A substantial viscosity increase at ambient temperature could indicate that the material is unsuited for centrifugal pumps.
3. The *specific gravity*, (ratio of the weight of the fluid compared to the weight of an equal volume of water), of the material at pumping temperature and ambient temperature.
4. The *pumping temperature* during normal operation. The range over which the temperature of the material could vary during pumping operations may be an important factor. The *vapour pressure* (the pressure at which the fluid becomes vapour) of the fluid measured at the pumping temperature is also an important characteristic.
5. A number of *other items* indicating the nature of the material. These include toxicity, explosive nature, entrained gases, and the presence of abrasive particles. If there are over 3% solids by volume the fluid may qualify as a slurry and require special pump design.

For this Topic, we will concentrate on problems created by materials pumped in water supply and waste-water operations.

WATER PUMPING

Water pumping systems are the most common of all pumping systems in plant operations. Water is a homogenous and relatively non-corrosive liquid and presents few problems to a pumping system. To transport water, a wide range of pump types including *positive displacement* or *centrifugal* pumps can be selected.

Water must often be pumped in great quantities. When a centrifugal pump is operating at high capacity, low pressures may develop at the impeller eye or vane tips. If the pressure in these regions falls below the water vapour pressure, bubbles of vapour may form in the water. As the water moves to a region of higher pressure the bubbles will collapse. This formation and collapse of vapour bubbles is called *cavitation*. Because the bubble collapse is so sudden, the water will hit the impeller vane with such extreme force that it is likely to gouge out small pieces of the impeller. In addition to this pitting of the impeller, noise and vibration will be created. Cavitation may be reduced or eliminated by reducing the pumping rate. If cavitation is not remedied, serious mechanical damage to the pump will result.

Suspended or dissolved material in the water may cause problems. Sand grains suspended in the water pumped from a well could cause *abrasive damage* to the pump. Submersible pumps are most susceptible to this kind of wear. The running clearance of submersible pumps is normally 0.004 inches. Sand particles in this size range can cause abrasive damage by scoring the bearing surfaces. A simple test to determine

if there is a sand problem can be conducted by filling a chemical (32 oz.) sample bottle with the water pumped and allowing the sediment to settle. If the sand covers the bottom of the bottle to a depth of one grain thick then the well pump is pumping water with more than the recommended concentration of sand. The only means of reducing sand being pumped from a well is by reducing the pumping rate. However, in doing this the operator must ensure that the discharge velocity of the water is high enough to keep the remaining sand in suspension all the way to the surface so that it does not settle out in the well.

Chemicals dissolved in water, such as chlorine and fluorides, make the water more corrosive and over long periods of time may cause *corrosive damage* to pumps. This potential problem should be given particular attention in water pumping systems where the chemical is added just before the water pump and the pump itself is used for mixing the chemical with the water. In this situation parts of the water pump exposed to higher than normal concentrations of the chemical may be subject to corrosive attack.

SEWAGE PUMPING

Generally, sewage is not pumped over great distances or at high pressures. The low head requirements of most sewage pumping systems as well as the pump's ability to pass small solid objects make the centrifugal pump better suited for this application. However, special consideration must be given to the variable nature of sewage in designing and operating a sewage pumping system. Unlike water, sewage is a heterogeneous mixture that may contain trash, rags, twigs, stones, etc. One must ensure that sewage pump will not be damaged by these objects. Perhaps a bar screen ahead of the pump will be required to remove the large objects. It is important that these bar screens be cleaned regularly. The impeller of a centrifugal sewage pump must be of a special design with large openings to allow solid objects and stringy material to pass through the pump without jamming it. Sewage, especially sewage containing storm water from a combined sewer system, contains large amounts

of sand and grit. As discussed earlier, this grit can cause abrasive damage to pumps. Most sewage pumps are designed with *greater tolerance* (i.e. greater amounts of clearance) and constructed with abrasion resistant alloys. Sewage may from time to time contain high concentrations of very corrosive industrial wastes. Frequently in sewage pumping systems the pump and perhaps the pump motor too (e.g. submersible sewage pump) will be completely immersed in the sewage. For this reason, the pump impeller, pump casing and any supporting structure should also be constructed of corrosion resistant alloys. Strict enforcement of the Sewer Use By-Law may protect sewage systems by reducing the concentrations of corrosive industrial wastes discharged to the sewers.

SLUDGE PUMPING

Sludge pumping systems have long been familiar to water pollution control plant operators. With the possibility of requirements for treating water treatment wastes, water supply plant operators will become more involved with sludge pumping. These sludges vary greatly in solids content but generally are of higher viscosity; that is, they are fairly thick and have more resistance to flow than water, but are still fluid when pumped. Some sludges may contain coagulation chemicals or polymers, which will further increase the viscosity of the sludge. Basically, the pumps used for sludge pumping applications are of the positive displacement variety including both *rotary* and *reciprocating* types.

Reciprocating pumps are particularly well suited for pumping viscous fluids. This type of pump adds energy to a fluid system by means of a piston acting against a confined fluid. The viscous fluid coating the cylinder walls serves as an additional "packing". Rotary pumps are also well suited for high viscosity fluids. This type of pump traps a quantity of fluid between rotating gears or lobes and moves it along towards the discharge point. Some lubricating action by the viscous fluid decreases wear of the pump parts.

The positive displacement type sludge pump must be protected from excessive quantities of abrasive grit that might accumulate in the sludge. For this reason, the grit removal facilities that are included at the influent of water pollution control plants should be operated in the most efficient manner.

Centrifugal pumps are less effective in pumping viscous fluids. The centrifugal pump is so called because the pressure increase in the fluid generated by the pump is due largely to centrifugal action. During flow through the rotating impeller the fluid receives energy from the vanes, resulting in an increase in both *pressure head* and *velocity head.* However, since a large part of the energy of the fluid leaving the impeller is velocity head, it is necessary to reduce the velocity of the fluid and transform the velocity head into pressure head. This is accomplished in the spiral shaped volute casing surrounding the impeller which provides a gradually enlarging passage to effect a gradual reduction in velocity and increase in pressure. The difficulty in imparting velocity head to a slow flowing viscous fluid reduces the efficiency of centrifugal pumps for this application. When centrifugal pumps are used for higher viscosity fluids, there is a marked decrease in pump efficiency and capacity and an increased need for more horsepower.

CHEMICAL PUMPING

In water supply and water pollution control operations there are a wide variety of chemical pumping systems. As discussed earlier, it is necessary to consider the nature of these chemicals before pump selection. Pumps can be constructed of cast iron, cast steel, fabricated steel, bronze, brass and other alloys, molded rubber, fiberglass or any other material that will be compatible with the chemical being pumped. Pumps handling corrosive chemicals require non-corrosive construction materials or internal protective

coatings that the chemical will not attack. Special sealing devices are also necessary.

Chemicals used in water supply and water pollution control operations such as alum, ferric chloride, hypochlorite solution, fluoride solution, polymers, etc., must be fed to the water or sewage in accurate dosages. This requires a pump of very special design and construction called a *metering pump*. Metering pumps are usually positive displacement pumps generally classified as two main types - *plunger (or piston)* and *diaphragm*. The prime feature of these positive displacement pumps is that a definite quantity of chemical will be delivered for each stroke of the piston or diaphragm. The quantity of chemical will depend only upon the volume of the cylinder and the number of times the piston or diaphragm moves through the cylinder. On the other hand a centrifugal pump operating at a constant speed can deliver a variable volume of fluid depending on the head.

Most metering pumps are designed with *close tolerances* (i.e. minimum amounts of clearance) between the pump casing and the internal parts. To maintain these close tolerances, it is sometimes necessary to strain or filter the chemical being pumped beforehand. If the chemical pumped is not strained, one must ensure that it is of high quality and does not contain particles or crystals that could damage the metering pump.

The specific gravity of the chemical will have to be considered in selecting the pump head. Equal pressures created by two different fluids require different heads. A ferric chloride solution can have a specific gravity of up to 1.5 (i.e. the ferric chloride solution can be one and one-half times heavier than water). Therefore the pump selected to pump ferric chloride solution to a certain height would have to generate approximately one and one-half times as much head as a water pump in the same situation.

Because of their precision construction, metering pumps will not tolerate extreme changes in the temperature of the chemicals they handle. Chemicals pumped at low temperature will show different pump capacity than the same chemicals at high temperatures. As the temperature of the chemical being pumped changes, the setting of the metering pump will have to be checked and adjusted if necessary to ensure proper dosage. In addition, the pumping temperature of certain chemicals like ferric chloride and alum must be carefully maintained above specified limits ($45^{\circ}F$ or $7^{\circ}C$) to prevent crystallization of the chemical which could cause damage to the metering pump.

SUBJECT:

PUMP SELECTION

TOPIC: 2

PUMPING SYSTEM CHARACTERISTICS

OBJECTIVES:

The trainee will be able to:

1. **Define various terms which apply to the pumping of liquid.**
2. **Calculate available NPSH, given the factors involved in a system.**
3. **Discuss the various components that make up the system head.**
4. **Develop and draw a system head curve.**
5. **Interpret curves showing pump characteristics.**
6. **Use a system head curve in pump selection.**

PUMPING SYSTEM CHARACTERISTICS

BASIC THEORY

General

Pumping involves the addition of kinetic and potential energy to a fluid for the purpose of moving if from one point to another. The amount of energy imparted to the liquid depends on the characteristics of the pump. This addition of energy to the liquid will cause it to do work such as flow through a pipe or rise to a higher level. In any system of piping-process installation there is an inherent natural opposition to flow or "system head", the various vertical heights through which the fluid must be lifted as well as the friction losses occurring in the components of the system as a result of flow.

In effect, centrifugal pumps operate on the same basis as a boy swinging a pail full of water in a circle. Put a hole in the bottom of the pail and a stream of water is projected from the bottom. The faster the movement of the bucket the further the water will carry; the wider the hole, the more water that will flow through.

Converting this into centrifugal pump terms, the head developed by the pump will vary directly with outside diameter of the impeller. Similarly, pump capacity will vary with the size of the inlet opening and water passages. Thus, two pumps with the same diameter impeller could have widely different capacities, while still maintaining virtually the same pumping pressure or head. On the other hand, since head varies directly with the peripheral speed of the impeller, it is possible for two different sized impellers to develop identical heads, by running the smaller impeller faster to develop the same peripheral speed.

This third factor is particularly important. For example, if a pump requires 10 hp at a given speed, doubling the speed of the pump would boost horsepower requirements to 80 hp. This is obviously impractical.

Capacity

Capacity is the quantity of water a pump will discharge against a given head. It is determined by the area through which flow occurs and by the velocity of flow. Velocity is dependent upon the peripheral speed of the impeller so that quantity is determined by the width of the impeller with constant speed. Of two impellers of the same diameter running at the same speed, the one having the greater width will deliver the greater capacity.

In specifying the pump capacity required for an installation, it should be stated in gallons per minute at the pumping temperature and any desired or imposed variation in the range of capacities should be clearly stated. Centrifugal pumps do not permit as much flexibility in capacity variations, without affecting pump efficiency, as does the reciprocating pump or other forms of displacement pumps. As a result, it is generally preferable to have the maximum efficiency of the pump occur at or near the normal capacity conditions.

Pressure

Pressures and their corresponding heads can be expressed either in absolute or gage units, such as 100 psig or 114.1 psi abs. Gage pressure is merely that measured above or below the atmospheric pressure while absolute pressure is gage pressure plus the existing atmospheric pressure.

The properties of water are not appreciably affected by pressure in the normal range. Gage pressure is therefore commonly employed in problems dealing with liquids except where suction conditions must be dealt with. Keep in mind that a pump does not draw water into its suction; rather, the absolute pressure pushes the water into the pump. In most applications it is feasible to work in terms of gage pressure but, occasionally, a complicated problem can be clarified by working entirely in absolute values of pressure.

Practically any unit could be used to describe pressure; however, feet of water and pounds per square inch are standard in the hydraulics industry. Pounds per square inch is the weight on one square inch. Feet of water is the height of water that would give the equivalent weight on a square inch. Since most hydraulic calculations are done in feet of water, this is the term generally used to describe pump performance. *It would take 2.31 feet of water to give a pressure of 1 psi.*

If the liquid is other than water, its specific gravity in reference to cold water is generally known or can be determined and the column of liquid equivalent to 1 lb. per square inch pressure can be calculated by dividing 2.31 by the specific gravity of the liquid.

$$\text{Pressure (psi)} = \frac{\text{Head (feet)} \times \text{Specific Gravity}}{2.31}$$

$$\text{Head (feet)} = \frac{\text{Pressure (psi)} \times 2.31}{\text{Specific Gravity}}$$

Specific gravity has an effect on the height of a column of various liquids for equal pressures. Thus a pump which must handle 1.2 specific gravity brine against 100 psi net pressure would in effect raise a water column 193 feet. If the pump has to handle water against the same net pressure it would in effect raise the water column 231 feet, while a pump handling 0.75 specific gravity liquid against the same net 100 psi pressure would raise the water column 308 feet.

It is obvious that if the pump designed to handle water was applied on brine service it would develop 231 feet head of brine or 120 psi pressure while if it was applied to pump 0.75 specific gravity gasoline it would develop 231 feet head of gasoline or 75 psi pressure.

Vapour Pressure

The vapour pressure of a liquid at any given temperature is that pressure at which it will flash into vapour if heat is added to the liquid, or conversely, that pressure at which vapour at the given temperature will condense into liquid if heat is subtracted.

For water and other homogeneous liquids the vapour pressure has a definite value at any given temperature. Tables are available which give the vapour pressure of such liquids over a wide range of temperatures. Certain mixed liquids however such as gasoline are made up of several components each having its own vapour pressure and partial vapourization may take place at various pressures and temperatures.

If the pressure in a pumping system is not equal to or greater than the vapour pressure of the liquid, the liquid will flash into a gas. Thus, pressure must be available on the suction side of the pump when handling hot water or volatile liquids.

Suction Limitations

The importance of keeping within the suction limitations of any pump (centrifugal, rotary, piston) cannot be emphasized too greatly. A pump, by creating a vacuum at the suction (impeller eye on a centrifugal) utilizes atmospheric pressure (14.7 P.S.I. at sea level) to push the liquid into the pump. Because of this, the suction lift is limited theoretically to 33.9 ft. of water maximum (14.7 P.S.I. x 2.31 ÷ SG (1.0) = 33.9' water). Internal pump losses reduce this limitation

even more. The dynamic suction lift should be calculated carefully at the required capacity to make sure that it is within the pump's capabilities. Even systems taking suction from a source above the pump can cause trouble when friction losses are too great. Always keep the pump as close to the liquid source as possible. Many pump performance curves will show the maximum practical dynamic suction lifts for a given pump or for given capacities from the same pump. Since the limitation is based on internal pump losses also, it can be seen that in any given pump the recommended suction lift is reduced as flow increases.

Before discussing various considerations related to pumping systems it should be noted that:

1. *capacity varies as the speed or impeller diameter.*
2. *head varies as the square of the speed or impeller diameter.*
3. *horsepower varies as the cube of the speed or impeller diameter.*
4. *heads can be measured in various units, such as feet of liquid, pounds per square inch pressure, inches of mercury and other depending upon the field and the units of measurements of the country.*
5. *pressures and head readings can be in gage or absolute units.*
6. *the difference between gage and absolute units is affected by the existing atmospheric pressure and thus by the altitude.*
7. *in handling liquids, the pressure at any point in the system can never be reduced below the vapour pressure of liquid.*

HEAD

The term "head" by itself is rather misleading. It is commonly taken to mean the difference in elevation between the suction level and the discharge level of the liquid being pumped. Although this is partially correct, this interpretation does not take into account all of the conditions that should be included to give an accurate description. In any pumping system the liquid must be moved through pipes or conduits which offer certain resistances or, in other words, have certain frictional losses. This energy dissipation, or head loss, is called a friction head while that energy which has been converted into velocity energy is called velocity head. Thus static heads, pressure heads, friction heads, and velocity heads may all be encountered. On the other hand, when considering a pump by itself, "head" is a measure of the total energy imparted to the liquid at a certain operating speed and capacity.

See Glossary for definitions of head terms.

NET POSITIVE SUCTION HEAD (NPSH)

The Net Positive Suction Head (NPSH) combines all of the factors limiting the suction side of a pump; internal pump losses, static suction lift, friction losses, vapour pressures and atmospheric conditions. It is an important factor in pump selection and one must differentiate between Required NPSH and Available NPSH.

Required NPSH refers to internal losses and is determined by laboratory tests. It varies with each pump and with each pump capacity and speed change. The greater the capacity, the greater the Required NPSH. The manufacturer must always specify the Required NPSH.

Available NPSH is a characteristic of the system. It can be calculated, or on an existing installation it can be determined using vacuum or pressure gages. By definition it is the total suction head determined at the suction nozzle

minus the vapour pressure. Since there are also internal pump losses, the Available NPSH in a system must exceed the pump Required NPSH or reduction in capacity and efficiency, noise vibration and cavitation will result.

To calculate the Available NPSH

NPSH (Available)	=	*Sum of Positive Factors*	-	*Sum of Negative Factors*

Positive Factors - *static suction head (if any)*
- *atmospheric pressure (if open or vented tank or sump)*
- *positive pressure (evaluate) (if closed pressurized tank) (at suction)*

Negative Factors - *vapour pressure*
- *all friction losses*
- *static suction lift*

All terms must be in feet taking into consideration the specific gravity of the liquid being pumped.

The purpose of NPSH ratings and calculations is to ensure that there is sufficient pressure on the fluid being fed to the pump so that the liquid does not boil in the suction system.

SYSTEM HEAD

One of the most important concepts to be understood in the correct application of centrifugal pumps is that of "system head", the natural opposition to flow inherent in any piping-process installation. In feeding into a network of piping, a pump works against a head imposed upon it by that network. The overall network is called, for our purposes, the "system" and it includes the pipe, fittings, valves, tanks and other components which may be in the flow path.

The total head of a system against which a pump must operate is made up of the following components:

1. Static head.
2. Difference in pressure existing on the liquid.
3. Friction Head.
4. Entrance and exit head losses.
5. Velocity head.

Static Head

To illustrate, consider a condition where we want to bring water at a certain rate from a source of lower elevation to some reservoir or water tank at a distant site and at a relatively much high elevation. To do this, in the most practical and economical way, a pump is used to move the water from the source through the pipe and eventually into the reservoir or tank. Before the size or type of pump can be determined, one must find out how much energy is required by the water to move it to the elevated tank; or what are the obstacles or elements against moving the water from one point to another?

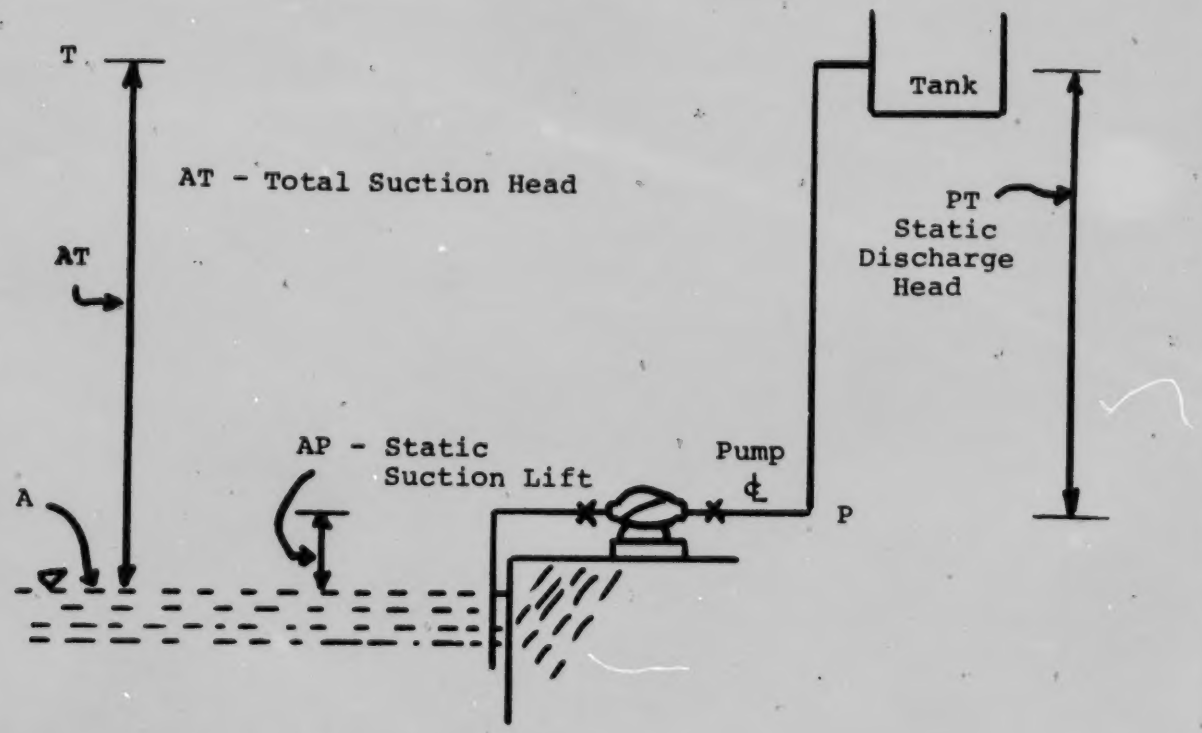


Figure 2-1 STATIC HEADS
(Suction Level Below Pump ℄)

In Figure 2-1 , water is pumped from source A to an elevated tank. The vertical distance, which the water has to travel, measured from the free top water level at A to the highest point of free discharge at tank is called the total static head. In this particular case, it is represented by distance $\overline{AT}$. Here it should be noted that the total static head is made up of the static lift, which is represented by distance $\overline{AP}$ and static discharge head by $\overline{PT}$.

If the source of supply is above the centre line (℄) of the pump the "static section left" is commonly referred to as the "static suction head". See Figure 2-2.

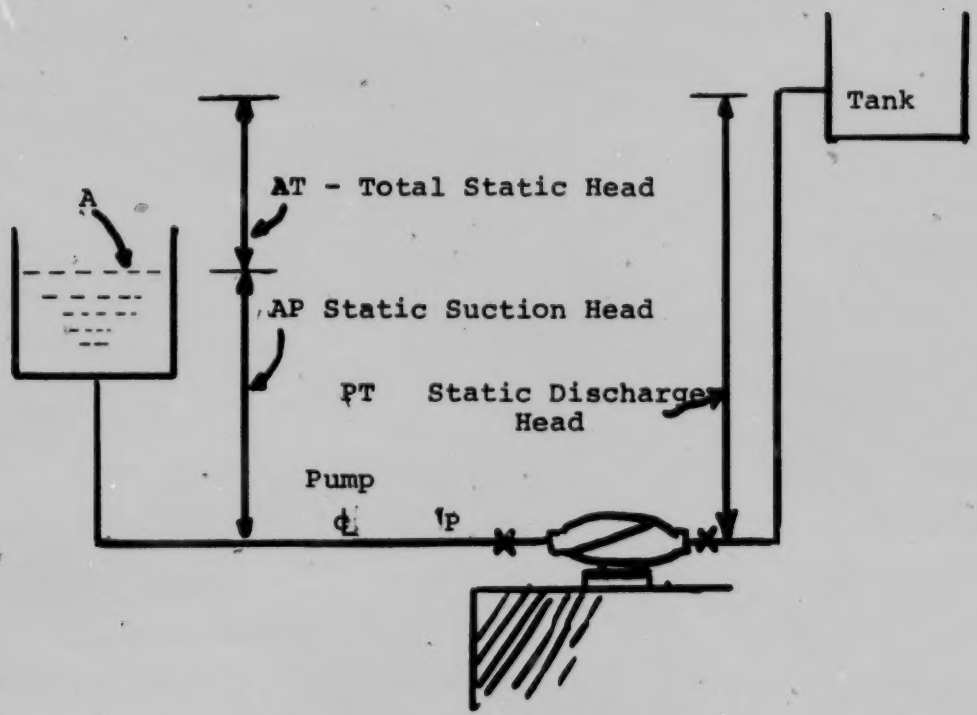


Figure 2-2 STATIC HEADS
(Suction Level Above Pump ℄)

Difference in Pressure

If either the suction or discharge liquid level is under a pressure other than atmospheric, practice varies as to whether this pressure should be considered at part of the static head or considered separately. The latter generally permits a clearer picture of the system.

Friction Head

Another element to overcome is friction, which is a kind of force which tends to slow down a body in motion. In this system, that force takes the form of a resistance to flow of water in pipes and fittings. That force or pressure required to overcome such resistance is called the "friction head". Its magnitude in terms of feet of the liquid being moved varies as the amount or rate of flow of the liquid.

Whether or not it can be ignored depends upon the accuracy wanted and upon the accuracy of the pressure readings that can be made.

Prepared tables are available giving friction heads for various rates of flow through various sizes and types of pipe, expressed as feet of head per hundred feet of pipe. Friction loss factors are also given for various pipe fittings expressing the losses as equivalent to losses in specific length of straight pipe of the same size, or as percentage of velocity head.

The fact that pipes are made only in standard sizes materially affects design. Frequently, accurate design calls for in-between sizes, such as 1-3/4", but since these are not available, standard sizes must be used. Since it is a usual safety measure to use an oversized rather than an undersized pipe, friction losses through the system will be less than calculated.

There is a second reason for reduction in friction losses. The design of a system requires that the friction losses through the fittings, as well as through straight pipe, must be taken into account. The usual procedure is to add a percentage to the measured pipe length. This percentage varies considerably, depending upon the size of the installation, but experience indicates that the addition for the fitting is usually too large. As a result, the system actually has less friction loss than calculated.

Since pumps are selected on the basis of the CALCULATED friction loss, it is obvious that oversized pipe and too great an allowance for friction through the fittings will result in a pump having more capacity than required. The net results of an oversized pump are generally undesirable. In the first place, more money than necessary is expended for a larger unit. Second, the attempt to assure safety by oversizing frequently causes noise trouble because of the resulting increase in water velocity.

Entrance and Exit Losses

Usually the supply of a pump comes from some form of reservoir or intake chamber. The point of connection of the suction pipe to the wall of the intake chamber, or the end of the suction pipe projecting into the intake chamber is called the entrance of the suction pipe. The friction loss at this point is called the "entrance loss". The magnitude of this loss depends upon the design of the pipe entrance, a well-designed bell mouth resulting in the lowest possible loss.

Likewise on the discharge side of the system where the discharge line terminates at some body of liquid, the end of the discharge pipe is called the exit. Generally the end is the same size as the rest of the discharge piping and the velocity head of the liquid is entirely lost. In some cases the end of the discharge piping is a long taper so that velocity can be gradually reduced thus reducing the "exit loss."

Some consider entrance and exit losses as part of the friction head while others consider them separately to ensure that they are not overlooked. Considering them separately has the advantage that it can be easily seen if either or both losses are excessive.

Velocity Head

This is the head of the liquid being pumped due to velocity or the equivalent distance in feet through which water would have to fall to acquire that velocity. Thus velocity head can be calculated as follows:

$$h_v = V^2/2g$$

Where V = velocity of water through the pipe in feet per second.

g = acceleration due to gravity (32.2 feet per second)

h_v = velocity head in feet.

Velocity head in high head pumps is relatively small while in low head pumps, it is relatively high.

System Head Curve

The system head curve graphically presents the relationship of conditions discussed under System Head. The head H is plotted against capacity Q to obtain the "system head curve" or the "system demand curve" as shown in Figure 2-3.

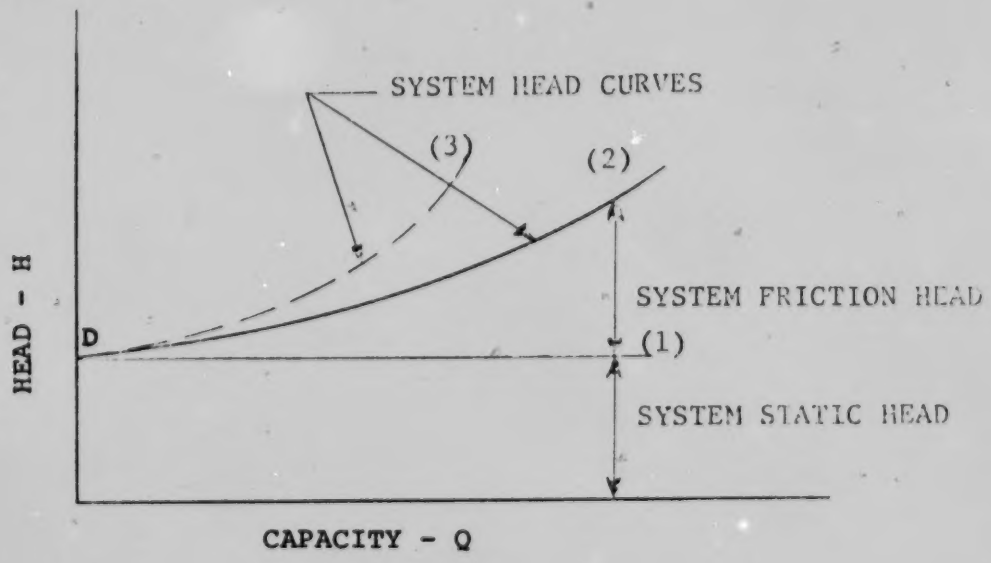


Figure 2-3 SYSTEM HEAD CURVE

If there were no friction losses along the piping, the system head curve would be represented by a horizontal straight line shown by line (1). With friction losses, the curve will be line (2). Now, if another piping system is used maybe with smaller pipes and fitting, the friction loss will increase for the same amount of flow as shown by the dotted line (3).

Note that the system head curve has a parabolic form since friction loss varies roughly as the square of the change in capacity. If the cross-sectional area of the pipe is assumed to be constant, friction loss varies roughly as the square of the change in liquid velocity through the pipe at the outset. It must be understood that any value assigned to friction loss can only be an approximation since friction losses will vary with size and type of pipe and fittings, with the interior condition of the pipe and with the character of the fluid being handled. It is usual to base the friction loss on constants that have been found from the average of pipe 10 or 15 years old, thus allowing for friction losses in excess of those that will be obtained when the pipe is new. As a result, the pump is generally designed for excess head and delivers over-capacity when installed in a new system or in one which has not suffered from pipe deterioration.

It will be noted that if there were no static head involved in the system, and there is only the friction head to work against, then point D in Figure 2-3 would shift down to zero, as shown in Figure 2-4.

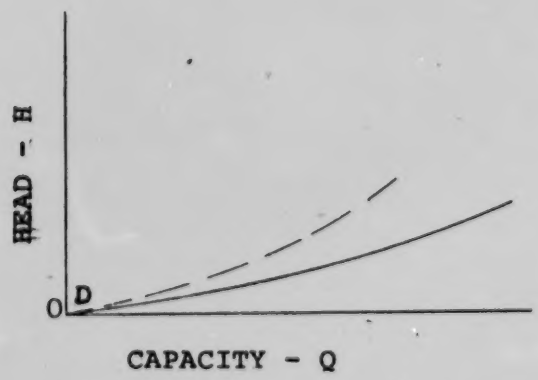


Figure 2-4 SYSTEM HEAD CURVE (No Static Head)

To plot a system head curve one must first establish the capacity desired and the head that the pump will work against. Assume that a pump is to be selected to pump 150 GPM at a 46 foot head. To plot the system head curve other flow/head relationships of this system can be calculated using the following formula:

$$\frac{\text{Original Head}}{\text{New Head}} = \frac{(\text{Original Flow})^2}{(\text{New Flow})^2}$$

If in a given system, the flow is doubled the head increases to 4 times the initial value.

Thus at 75 GPM the head is calculated as follows:

$$\frac{46}{x} = \frac{(150)^2}{(75)^2}$$

$$\frac{46}{x} = \frac{(2)^2}{(1)^2}$$

$$x = \frac{46}{4} = 11.5 \text{ feet head}$$

By similar calculations

Flow	Head
100 GPM	20.5'
125 "	32 '
175 "	63.7'
200 "	82 '

Plotting these values the system head curve shown in Figure 2-5 is obtained.

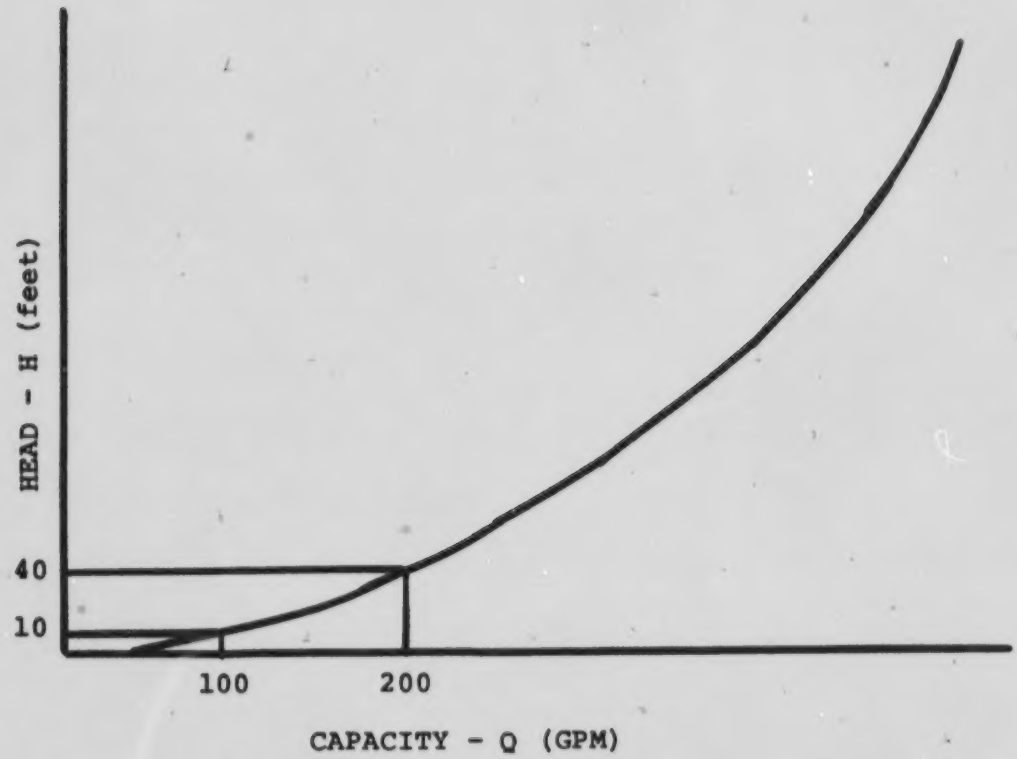


Figure 2-5 System Head Curve

Head Capacity Pump Curves

The manufacturer illustrates the performance of a pump by pump performance curves on a head capacity graph. The graph shows the interrelation of capacity, head, power and efficiency and is commonly known as the "characteristics of the pump".

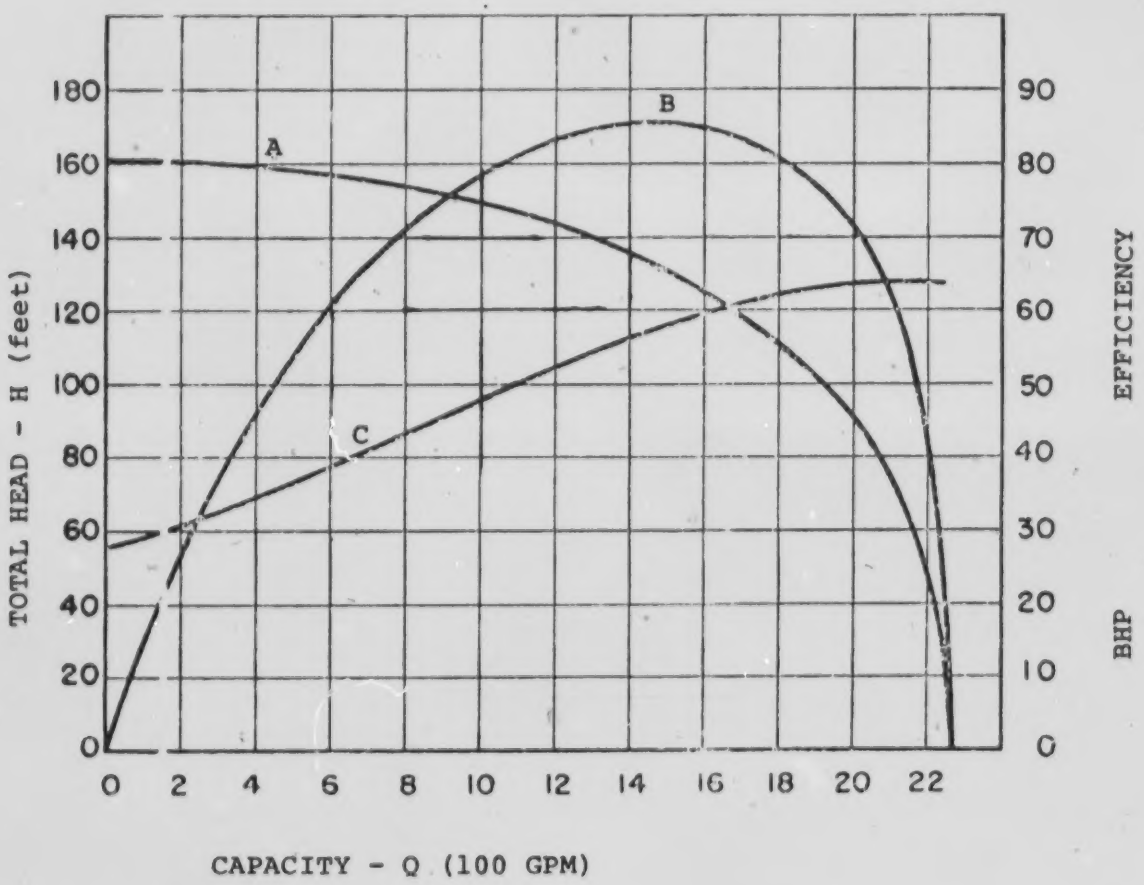


Figure 2-6 GRAPH-CHARACTERISTICS OF PUMPS

The line (A) sloping down from left to right represents the varying quantities of liquid delivered by the pump, with variations in head or pressure. The intersection of this line, with zero capacity line on the left shows the shut-off head, or the head or pressure (160) developed by the pump when the discharge valve is shut.

The curve (B) showing the horsepower required to drive the pump slopes upward in the opposite direction, with the lowest point at the shut-off of the pump.

These two lines show the complete performance of the pump for the one speed for which the curve is plotted. However, for convenience, another curve (C) showing the efficiency curve shows the amount of usable work done by the pump in percent of power delivered to the pump shaft.

Pump curves can be plotted to show variations with changes of speed as well as changes in head and capacities. However, most electric motors operate at constant speed, so that the usual practice is to show the pump characteristic for a single speed suitable for the conditions for which the pump is made. The changes in capacity, head, and horsepower, for various speeds, can be quickly calculated if desired.

USING THE SYSTEM HEAD CURVE

Always remember that the operating conditions for a pump can best be determined by plotting the system head curve and the pump characteristic curve to the same scale on one graph. The operating point will always be at the intersection of the two curves. All pump installations can be represented graphically as being a system head curve upon which the characteristic head-capacity curve of one or more pumps has been superimposed. Some systems are more complicated to calculate than others; these may require the calculation of individual portions of the system separately for later addition graphically to obtain the overall system head curve.

Once the total head is known (and having considered all other factors), a pumping unit can be selected. A unit with a known head-capacity characteristic curve is examined. The required capacity (Q_a) and head (H_a) from the system head curve is compared with that on the head capacity characteristic curve by superimposing both curves on a graph as shown in Figure 2-7 .

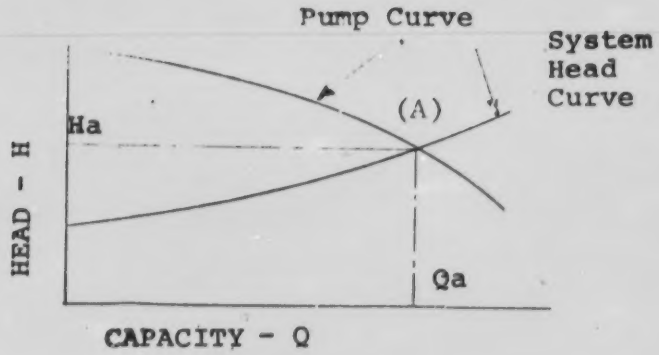


Figure 2-7 COMBINED PUMP/SYSTEM HEAD CURVES GRAPH

If the pump is rated at the capacity and head where the pump curve intersects the system head curve, then the pump matches the system.

On the other hand, assume as shown in Figure 2-8 that the required capacity 150 GPM and head (46 feet) mentioned earlier is at a point just above the curve (A) of the pump being considered. Should pump A be used or the next larger size pump B?

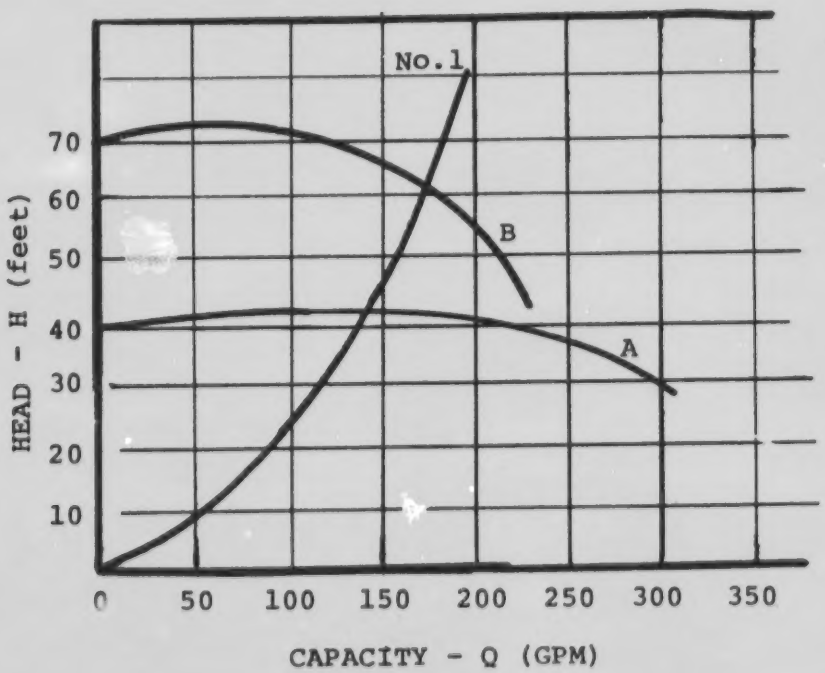


Figure 2-8 PUMP CAPACITY GRAPH

Line No. 1 representing the system head curve shown in Figure 2-8 is superimposed on the pump curve. It intersects the pump curve (A) at 140 GPM and 41.5 feet head and curve (B) where 175 GPM will be delivered at 62 feet.

Pump (A) could be safely selected because safety factors are deliberately included in the design of the pump.

One such inherent factor is in the carrying capacities assigned to pipe. Some tables provide such high factors of safety that the calculated friction loss at design flow may be too high by as much as 50%. Second, the allowance made for the resistance of the fittings is usually on the generous side. If accuracy is desired, a tedious series of calculations must be made, but, as stated earlier, the designer usually by-passes this work by adding a percentage to the measured pipe length. Generally speaking, this method is satisfactory.

The selection of pump (A) can therefore be justified by both the conservative values given in pipe capacity tables and by the practice of making large friction allowances for the fittings.

The net results of selecting an oversized pump (B) are generally undesirable. In the first place, more money than necessary is expended for a larger unit. Second, the attempt to assure safety by oversizing frequently causes trouble because of the resulting increase in water velocity.

PARALLEL OPERATION

Since examples will lend further clarification, consider these typical common applications. Often, an installation will include problems of capacity variation over a wide range. This can be accomplished by placing pumps in parallel to discharge at the same pressure into the same header. Each pump can be placed in service or removed according to the system demand at the time. One approach would be the

use of identical pumps placed in parallel. These would each develop the same head at any given capacity. When operating in parallel, the total capacity of two such pumps would be double the capacity of one pump at the head involved. This is illustrated graphically by Figure 2-9.

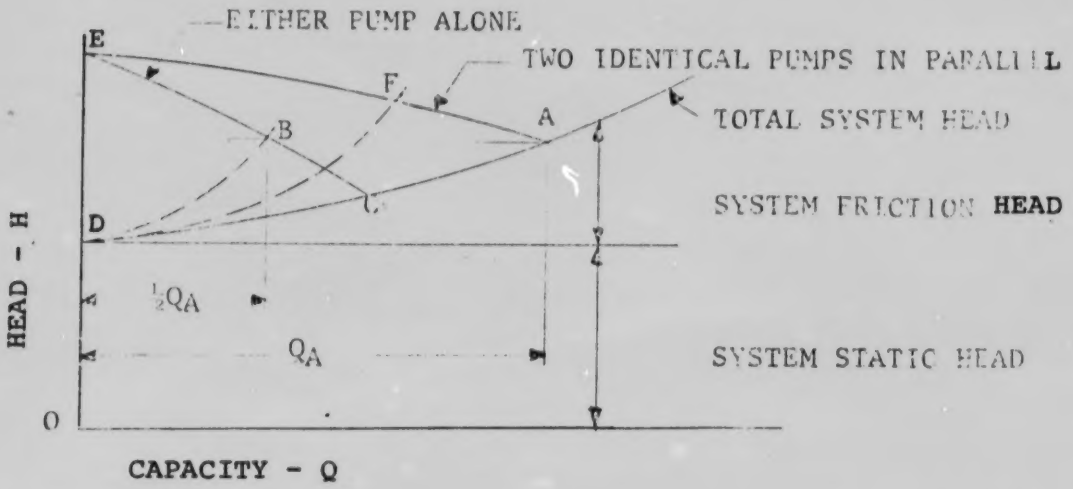


Figure 2-9 Capacity Curve Two Pumps in Parallel

The two pumps together operate on curve EA intersecting the system head curve at point A. Note the combined operating curve starts at the no-flow or "shut-off" condition, E, of a single pump. Each succeeding point on the curve is developed by doubling the capacity of a single pump at any given head.

Were a single pump to operate alone at its design capacity, and, therefore, at a head of A, its discharge valve could require throttling to create sufficient artificial friction loss to form a system curve DB. If the demand were to increase, the throttle must be made less severe until point C is reached. The system itself would limit the flow to this latter capacity. The determination of point C is important for, with it, all possible operating points of a single pump have then been determined and the pump's driver

can be sized to handle the maximum power requirement within the range EC. Even if the pump has been factory tested and has demonstrated far greater carry-out abilities and, depending upon the design, possibly greater power requirements, point C of the system head curve has determined the maximum power required for the pump when placed in the particular installation under consideration.

The development of the system head curve and a knowledge of demand variations to be expected can be of great assistance in determining the most economical division of the entire range into pump sizes needed. This can be done ideally when laying out a new system. For paralleling of the pumps to be accomplished properly, the units should be selected to have the same or nearly the same shut-off head. Otherwise, one pump having the higher shut-off head would tend to back the others off the line.

Such a system is represented by Figure 2-10. Pump #1 has the lower shut-off head and would operate at the shut-off condition at any capacity demand less than that of point B. The combined curve of the two pumps in parallel would be FBG. Were the capacity to decrease to B or below, pump #1 operates at the shut-off condition. It could thus endanger itself if not shut down promptly, or if provision had not been made to by-pass adequate flow to carry away the heat that would be generated.

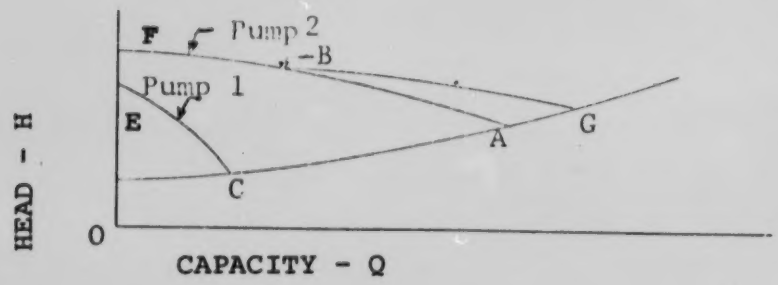


Figure 2-10 Effect of Operating Pumps with Different Heads in Parallel

This arrangement is somewhat typical of municipal water works systems that have experienced an expansion of facilities due to population growth in outlying areas necessitating longer lines, often extensions of older mains now too small but too expensive to replace. The result is increased friction requiring additional pumps of larger capacity and higher head as well to fulfill the increased demand.

It should be noted further that, in this example, the larger pump would be required to operate over the range of low capacities where it would not be at its best efficiency point, nor possibly as efficient as a smaller pump designed for those capacities. A solution to this aspect of the problem, as well as the matter of paralleling properly, is often found in the purchase of a new impeller for the smaller pump, this impeller having a steeper head-capacity characteristic, or, in other words, a higher shut-off head. Another possible solution may lie in stepping up the speed of the small unit, since head increases by the square of the change in speed of the pump. While a new and larger motor may be required, the cost will be easily justified in most cases, and will be considerably less than the purchase of a complete new pumping unit. In contemplating such a modification, full investigation of the particular pump's characteristics and design must be made with the manufacturer.

1. *By the use of the system resistance curve, the pump performance can be checked against system requirements eliminating the usual trial and error adjustments.*

2. *Oversized pumps can cause excess velocity in the system and noise results.*

3. *Formula for establishing points on the system resistance curve is*

$$V = \frac{H^2}{2g}$$

where "H" is the head, "V" is the velocity in gallons per minute and "g" is acceleration due to gravity 32 ft/sec/sec.

4. *If a capacity requirement for a system happens to be slightly higher than what a certain pump can deliver, in most cases, this pump can be used.*

SUBJECT: PUMP OPERATION

TOPIC: 3 TYPES OF PUMPS

OBJECTIVES:

The trainee will be able to:

1. Identify and recall the principal application of various types of

   a) centrifugal pumps

   b) positive displacement pumps.

2. Identify the major components of a centrifugal pump and recall the function of each.

3. Recall likely suitable applications of reciprocating pumps.

TYPES OF PUMPS

GENERAL

Basically pumps are categorized as either the centrifugal type or the positive displacement type (rotary or reciprocating). These types can be further classified according to the types of service for which they are designed or by features of their construction.

Pumps of the centrifugal type are:

1. Volute type centrifugal pumps. These are the most common type in use today. An impeller discharges the fluid into a progressively expanding spiral casing. This is proportioned to reduce liquid velocity, changing it to pressure head in the volute. Sub-classifications include open or closed impellers, single end-, or double-suction types, single or multi-stage. Single suction pumps have the liquid entering the impeller from one side. Double-suction pumps have liquid entering the impeller from both sides. In these cases, the impeller is built like two single suction impellers put back to back. Multi-stage pumps have two or more impellers on a common shaft, acting in series in a single casing. The liquid is conducted from the discharge of the preceding impeller or stage to the suction of the following stage, causing a pressure increase as it passes through each stage.

2. Diffuser type centrifugal pumps. These use stationary guide vanes surrounding the impeller. The gradually expanding passages change the direction of liquid flow, converting velocity energy to pressure head. Most common application today is in multi-stage, high pressure units. Efficiency is about the same as for volute-type. Both volute and diffuser types are relatively low capacity units, though a wide range of flows are available.

3. Axial-flow (or propeller-type) centrifugal pumps. These develop most of their head by the lifting action of the vanes. These low-head, high capacity units are essentially similar to Kaplan-type water turbines operating at high speeds. Usually of vertical design, they can be used in a variety of services, handling dirty liquids and those with solids contents.

4. Mixed-flow type centrifugal pumps. These are used mainly on large capacity, low-head installations. Usually built as vertical units, this type of pump uses both centrifugal force and the lift of the pump vanes to pump liquid. Impellers are single-end type, single or multi-stage. Either water or oil lubrication may be used on this type of unit, depending upon application.

5. Turbine type centrifugal pumps. These are higher capacity units with the impeller's vanes adding energy to the liquid. Use of this type of unit is largely restricted to clear liquids, with specific advantages where high-head operation is required. Both horizontal and vertical designs are available. Turbine pumps offer a cross between centrifugal and rotary design characteristics.

Rotary type positive displacement pumps are:

1. Gear type rotary pumps. These use two or more gears to provide positive-displacement, smooth flow movement of liquids. Operation is simple. Liquid fills spaces between gear teeth as they separate on suction side, is carried around and compressed as the teeth mesh. Gears may use spur, single- or double-helical teeth depending upon design. Like all rotaries, is suitable for handling viscous fluids. Two-, three- and four-lobe designs use synchronized turning of lobes to provide pumping action.

2. Screw type rotary pumps. These are available in single-screw designs (sometimes called progressive cavity pumps) as well as two- and three-screw designs. This type of pump can handle very viscous, nonabrasive fluids, including such materials as cement grout. Close tolerances maintained on screw type pumps make handling of abrasive materials difficult.

3. Vane type rotary pumps. These use vanes or buckets turned by a single rotor. Variations include swinging-vane (where hinged vanes swing out to trap liquid), sliding-vane where vanes are thrown against casing bore by centrifugal action, and shuttle-block pumps. Flexible vane pumps are also used for lower pressures than rigid-type vane pumps.

4. Cam-and-piston type rotary pumps. These use an eccentric with a slotted arm at the top. Shaft rotation causes the eccentric to trap liquid in the casing, discharging it through the slot. This provides the steady discharge flow common to most rotary pumps. Other eccentric designs include use of eccentrics in flexible chamber which pumps by a squeezing action, and the flexible-tube pump where a flexible tube is squeezed by a compression ring on the eccentric.

Reciprocating type positive displacement pumps are:

1. Direct-acting reciprocating pumps. These are frequently steam-driven units. Like all reciprocating pumps, they feature pulsating flow, relatively small capacity, and ability to handle high pressures. Increased head will decrease capacity of direct-acting units, unlike other types of reciprocating pumps. Direct-acting steam pumps have two sets of valves in the liquid end. Double-acting pumps are most common, with liquid being drawn in through suction valves as pistons move in, while liquid previously drawn in is discharged through the discharge valves.

2. Power-type reciprocating pumps. These are driven from outside through a crankshaft or other device. Capacities range from low to medium flows, at pressures up to very high. These may be single-acting or double-acting units. These units range from small adjustable-displacement types for metering and proportioning to large units designed for marine boiler feed service. Output curve of power-pump designs approximates a sine wave, while direct-acting types are relatively flat, with sharp drops at the end of piston stroke.

3. Crank-and-flywheel type reciprocating pumps. These are another major version of the power-type pump. The major difference is in driving mechanisms. The crank-and-flywheel is a specific type of drive, where a number of different mechanisms may be used for driving power-type pumps. Note: all reciprocating pumps can be single- or double-acting to smooth out pulsatings in flow. Duplex and triplex types are designed to smooth out flow still further. Special constant-delivery types are also available, which provide a flat output curve regardless of adjustment of stroke length.

The various types of pumps in each category are discussed in greater detail in the following paragraphs.

CENTRIFUGAL PUMPS

General

Because of their adaptability to a wide variety of operations, low initial cost and easy maintenance, centrifugal pumps make up the most widely used type of pump in industrial plants, as well as municipal water and wastewater operations. In certain cases changing an installed centrifugal pump to handle heavier or more viscous materials, such as sludge or liquids containing granular material, may only require installation of an impeller of different size and shape.

Figure 3-1 illustrates an end suction centrifugal pump and the direction of flow.

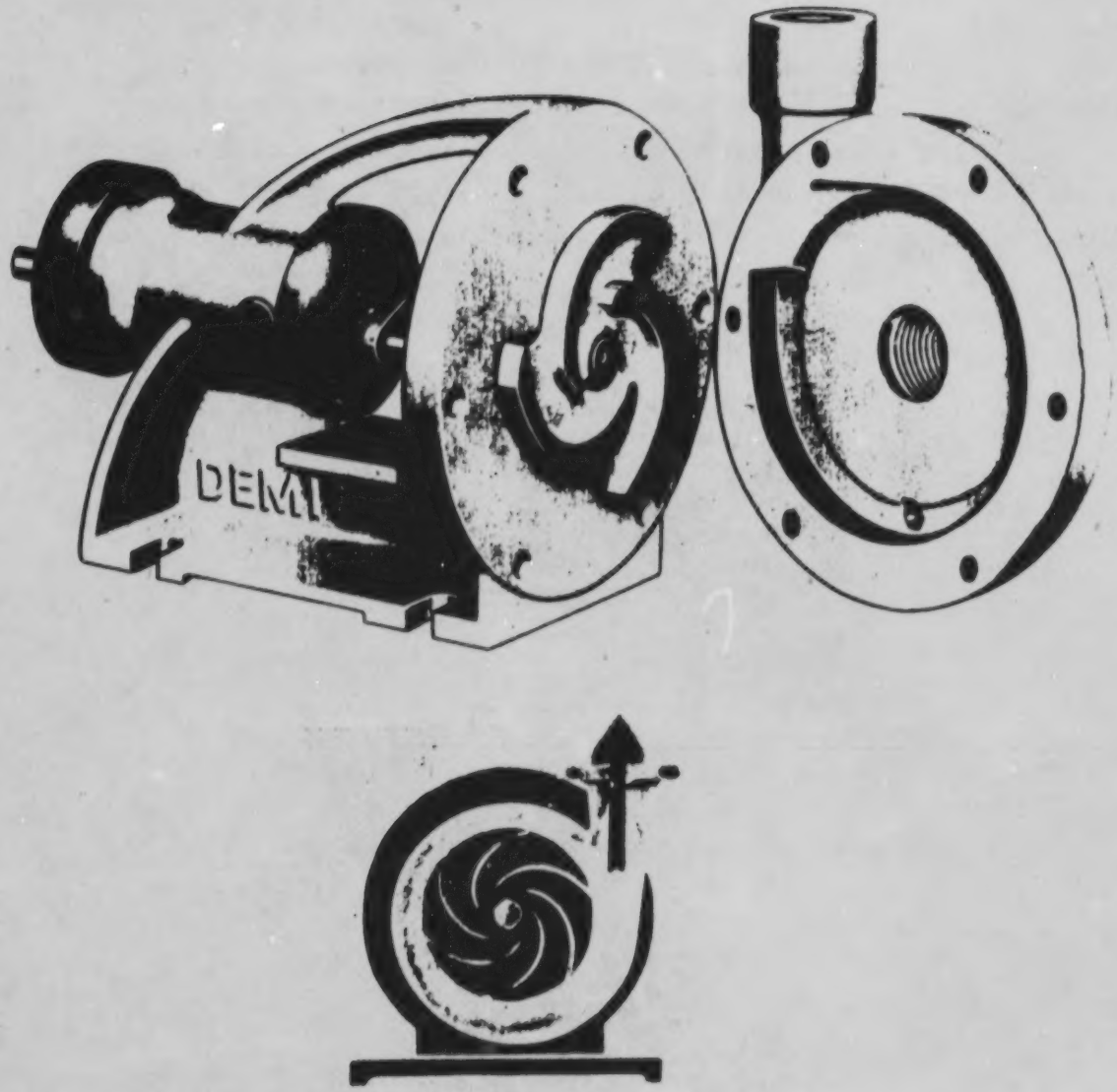


Figure 3-1

End-suction Centrifugal Pump and diagram showing the direction of fluid flow.

Figures 3-2 and 3-3 illustrate single stage pumps, which are equipped with either one suction inlet (Figure 3-2) or two suction inlets (Figure 3-3).

Figure 3-4 shows a multi stage pump, which may be constructed with either a single or double suction.

In these pumps the fluid is discharged from one stage to the next through internal passages in the pump casing. Each stage builds up the velocity of the fluid until the desired head is developed. A typical multi stage, single suction pump is illustrated in Figure 3-4.

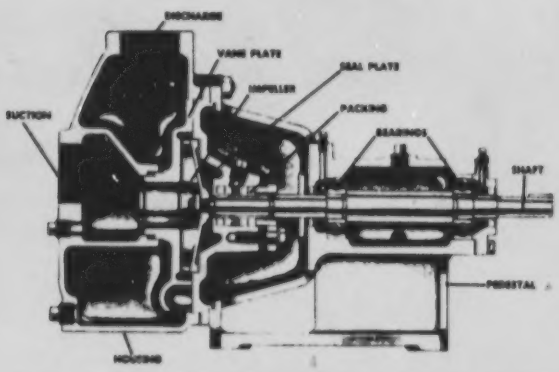


Figure 3-2
Single stage end-suction Centrifugal Pump.

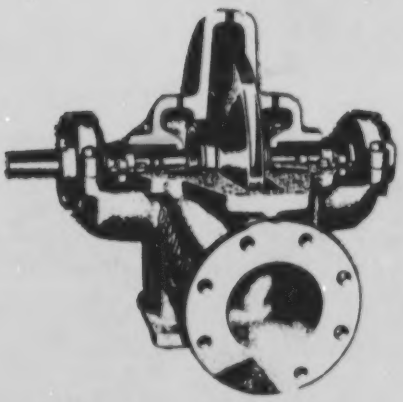


Figure 3-3
Double Suction Pump

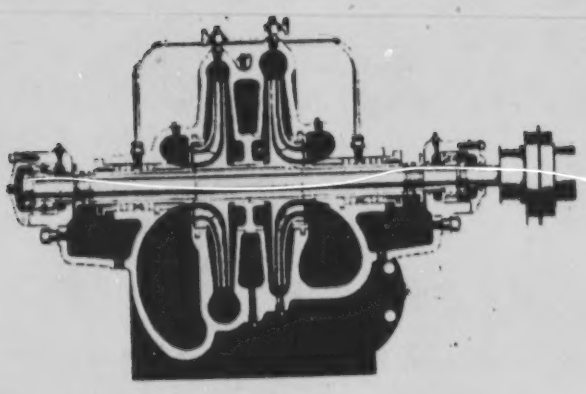


Figure 3-4
Two-stage Single Suction Pump

Pump Components

Although types of centrifugal pumps differ in design, components are usually common. Referring to Figure 3-2 the parts are:

1. Suction End (Pump Inlet)

   This is the point at which the material pumped enters the pump. It is normally located near the centre of the casing. The diameter (or size) of this opening partially determines the rate at which the unit could pump.

2. Impeller

   The impeller is that part of the pump which applies energy force to the material pumped to give it velocity and kenetic energy.
   The opening in the centre of the impeller is called the impeller eye. This is where the flow enters the impeller. The size of the eye partially determines the capacity of the pump.

3. Impeller Vanes

Vanes are blades of the impeller which direct the flow from the eye outward imparting the kinetic energy to the material pumped.

4. Impeller Shrouds

This component of the pump encloses the blades or the vanes of the impeller, and contains the flow material in the impeller.

5. Pump Casing

The casing is the enclosure surrounding the pump impeller, shaft and the packing gland. The casing directs the flow of liquid into and out of the pump. It consists of:

a) volute
b) head cover
c) suction cover

6. Discharge End

This is the side or the end where the pump discharges the fluid.

7. Pump Shaft

The pump shaft may consist of a part of a motor, or may be separate to the motor shaft. It may be supported by the motor bearings or the shaft may be supported by independent bearings.

8. **Wearing Rings**

The principal function of the wearing rings is to provide a replaceable bearing surface between the rotating impeller and the stationary casing. This reduces the build-up of heat between rubbing surfaces.

9. **Packing Gland**

The packing gland can be referred to as a seal in a pump. It can be one which uses loose or braided packing or one which has a mechanical seal. Its principal function is to seal the fluid in the pump.

Impellers

The pump impeller is the most important component of the pump. Its size, shape and operating speed determine the pump capacity.

There are two major differences in the shape of various impellers - they are the straight vane impeller and the curved or radial vane impeller. Common types of impellers are shown in Figure 3-5 . The straight vane impeller may have a single or a double shroud. The radial vane impeller is also manufactured in both open or closed design. The open-type impellers have the shroud only on the back side. The shroud may cover only part of the vanes or cover the complete diameter of the impeller.

The double shrouded impellers are used in both double and single suction pumps. The double suction-type is very similar to the single suction-type impeller. They differ in that the centre of the double suction impeller has only partial shrouds. The vanes on each side of this impeller are in matching position and join to form a single vane near the discharge edge of the impeller.

Figure 3-5
Common Types of Impellers

Pump Casings

Centrifugal pumps used in water and wastewater operations vary considerably in design and construction, depending on the application. Some of the distinct physical differences between various types of pumps are illustrated in Figure 3-6.

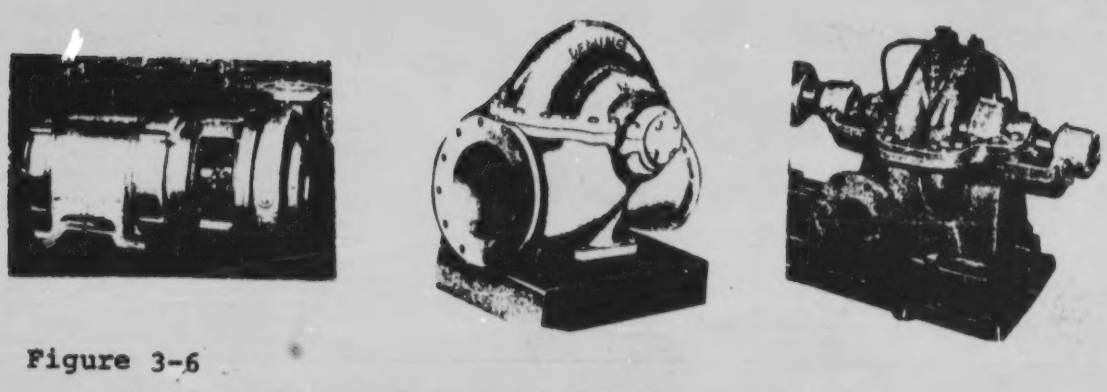


Figure 3-6
Various types of Centrifugal Pump Casings

Depending on the specific application of the pump, the pump casings are made of different materials such as cast iron, steel, bronze, as well as a number of non-corrosive and abrasion-resistant metal alloys.

Although the general principles of the centrifugal pumps are usually the same, the internal pump design may vary considerably. As an example, in the volute type casing, the internal water action tends to develop unbalanced radial

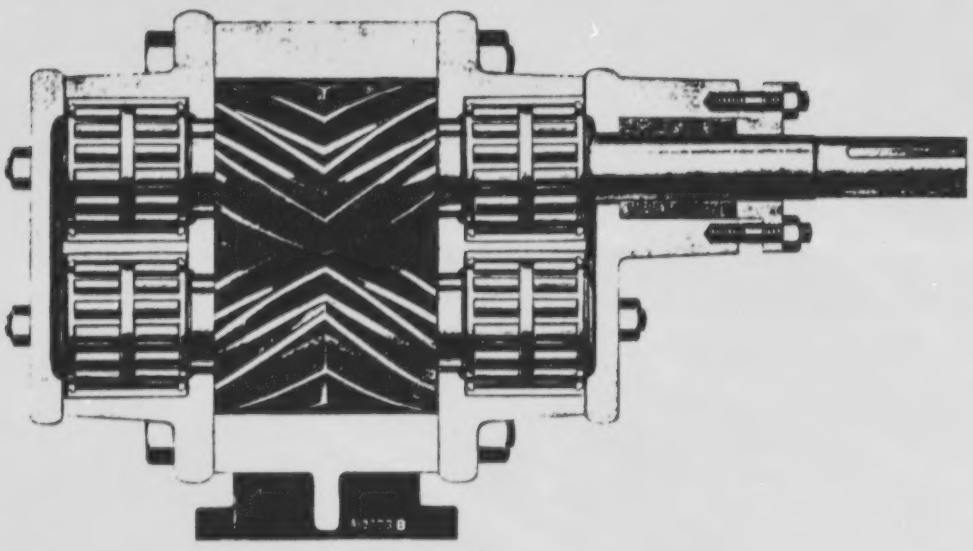


Figure 3-16(a)
Gear-type Rotary Pump with internal bearings.

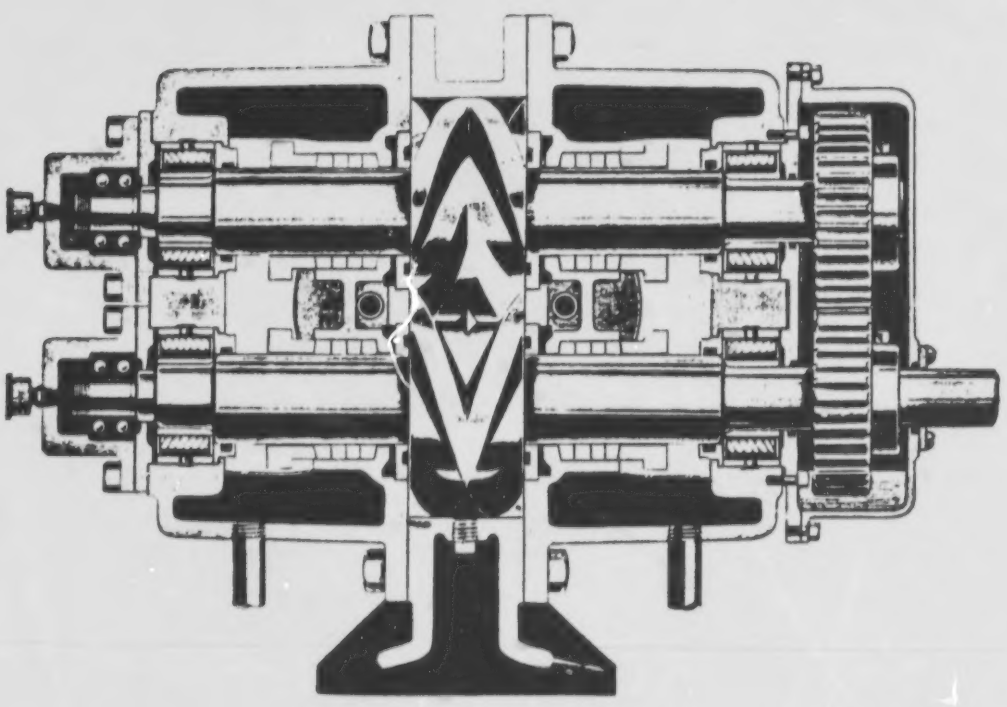


Figure 3-16(b)
Gear-type Rotary Pump with external bearings.

Courtesy of Worthington Corporation

forces, which may be damaging to the pump. To reduce these unbalanced forces, some pumps are constructed with a double volute. This feature provides another guiding vane for the water to pass through, thus splitting and balancing the internal radial forces of the liquid on the pump impeller, shaft and bearings, plus reducing some of the stress load on the casing walls.

The double volute guide vanes can be built into both solid and split-type casings. Also double volute guides are built into multi-stage pumps to balance the discharge head to the suction side of the next stage. A typical double volute casing is illustrated in Figure 3-7.

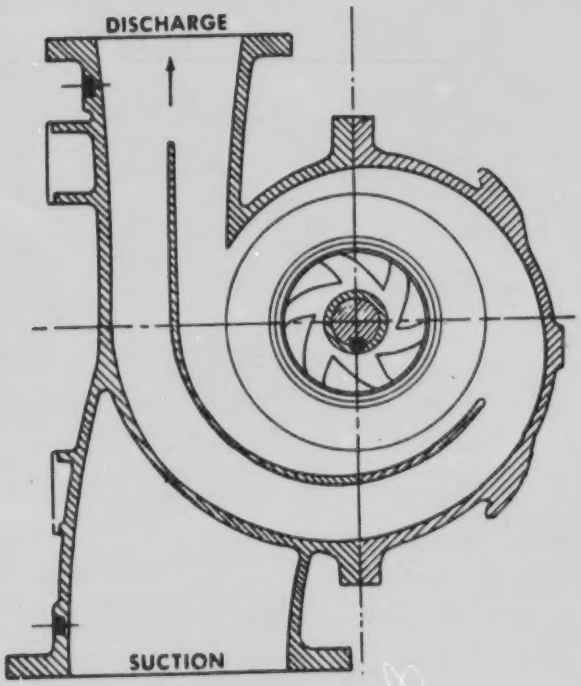


Figure 3-7
Double Volute Casing

In pumps which work against very high heads (pressure), the casings are further strengthened with ribs on the outside of the casing, placed usually at right angles to the direction of the flow.

Pump casings can be of either solid or split design, as illustrated in Figures 3-8 and 3-9. Pumps equipped with solid casings are usually end suction type and are always equipped with a removable cover or face place on the suction side for easy access to the impeller.

Figure 3-8
Solid Casing Design

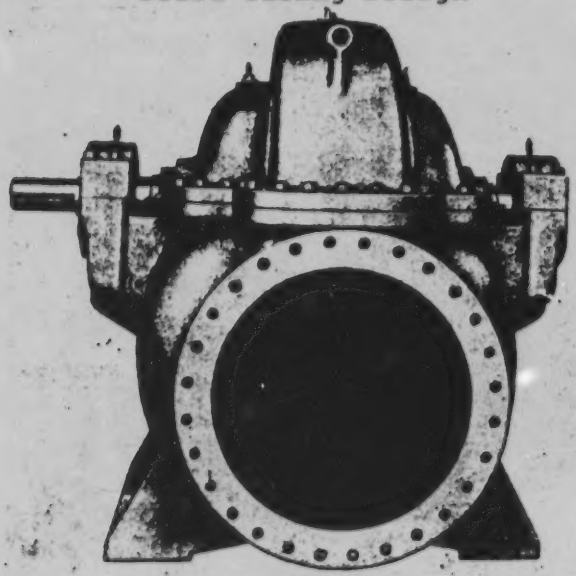


Figure 3-9
Split Casing Design

Pump casings consisting of split construction are normally called the horizontal or axial split. This type of design with a split on the centre line of the shaft allows for the removal of the upper half of the casing and provides access to the pump shaft, impellers and bearings.

Pump casings are also manufactured with a radial split. With the radial split, the casing can be assembled in segments to form one multistage pump shown in Figure 3-8.

Pumps which are cast complete with a supporting base usually have the direction of flow, horizontally or vertically, predetermined by its design. A pump which requires independent supporting framework may have its discharge point positioned in a number of different ways to fit in with the installation requirements.

Double suction pumps are normally constructed with both the intake and the discharge below the centre line. (Fig.3-10)

This pump can be equipped with the intake and discharge on opposite sides, or it may have an intake at the bottom and have a side discharge port.

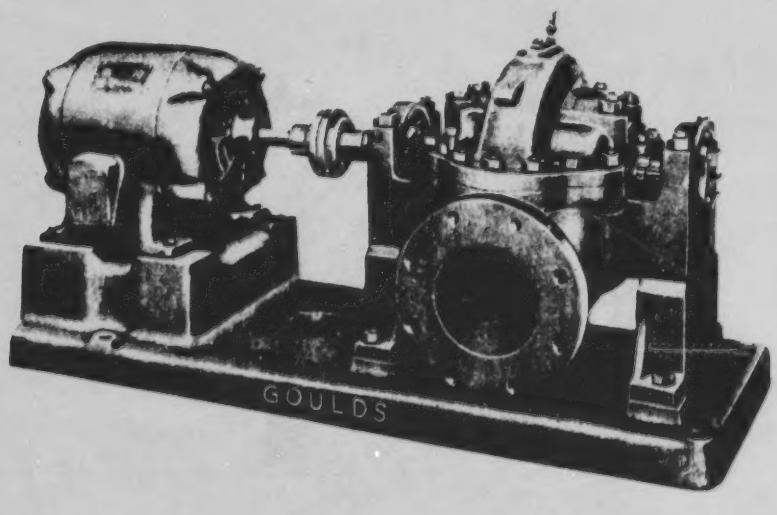


Figure 3-10 Double Suction Pump Casing

Wearing Rings

The wearing rings in the centrifugal pumps serve the following purposes:

1. It is a replaceable bearing surface between the rotating impeller and the stationary casing.

2. It reduces the heat between rubbing surfaces.

3. It provides a leakage point for fluid between the discharge and the suction side of the pump, allowing small amount of water to recirculate inside the pump. This recirculation counteracts some of the radial and thrust forces that build up within the pump. In most cases the wearing rings are designed to be adjustable so that a proper clearance between the impeller and the casing could be maintained.

The wearing rings are normally made of bronze or brass. They may be installed either in the casing or on the impeller, or on both depending on the design of the pump.

Pump Shafts Bearings

The shaft bearings, depending on the design of the pump, may be of sleeve, roller bearing or ball bearing type. Also, some types of pumps are equipped with special thrust bearings to eliminate the development of high thrust against the end of the pump. Multistage pumps with high pressure capacities are usually equipped with thrust bearings.

In low horsepower pumps, the impeller and the motor are on the same shaft. Therefore, in this case all radial and axial thrust must be absorbed by the motor bearings.

Large pumps usually have separate shafts and are coupled to the motor. The shaft is independently supported by its own set of bearings according to its design (Fig.3-11).

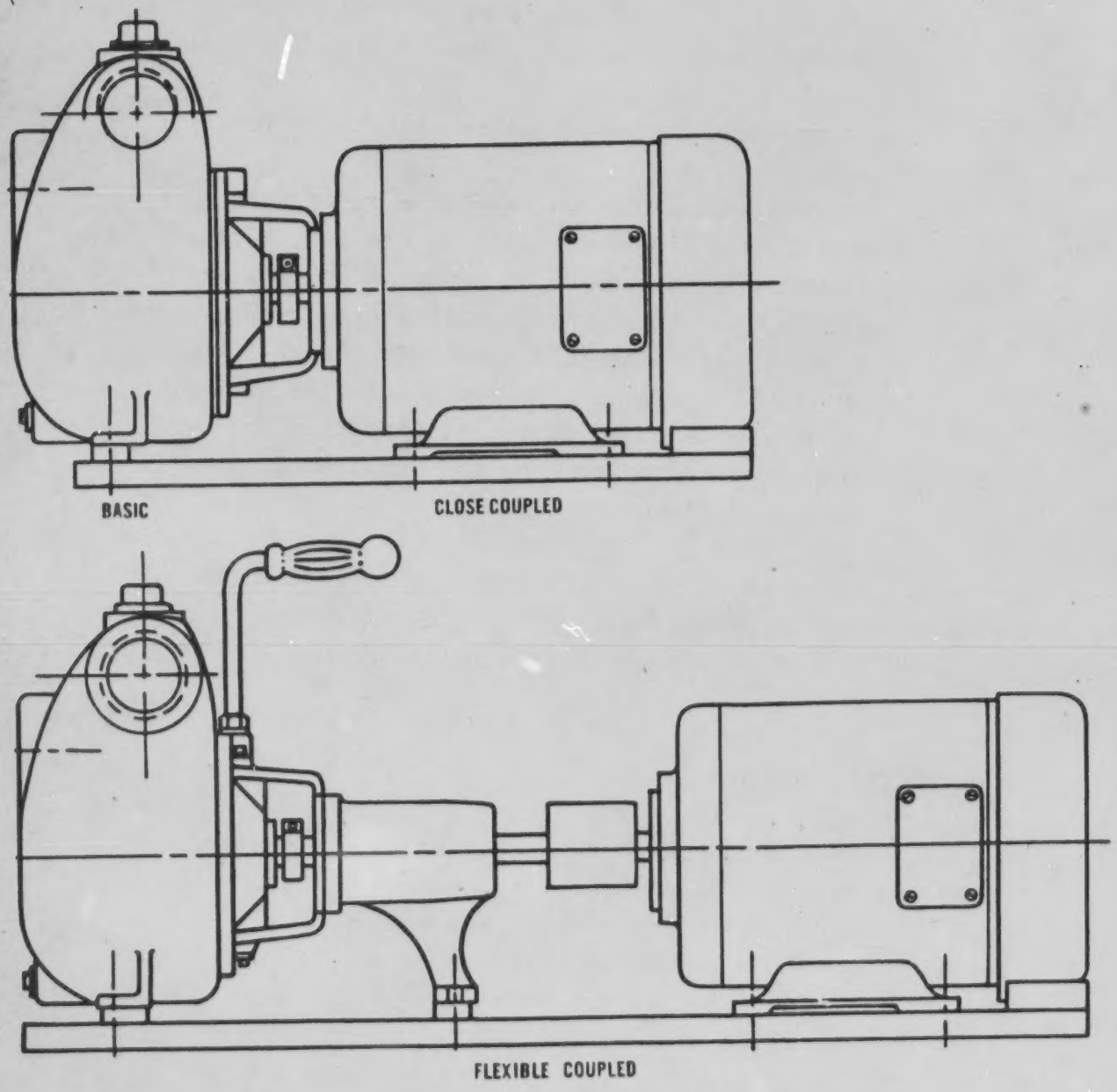


Figure 3-11

Typical Pump-to-Motor Couplings

PROPELLER AND TURBINE PUMPS

General

Although the volute type pump is the most common pump used in municipal water and wastewater operations, there are instances where this pump is not capable of delivering the required capacity or providing the required lift. For these applications either the propeller or turbine pump is selected.

The propeller pumps are classed as *Axial-Flow or Mixed-Flow*.

Axial-Flow Pumps

Axial-flow pumps are designed for installations where high volume and low head capabilities are required. This type of pump is often used in municipal water supply systems, or for irrigation purposes or dewatering of flooded areas. The pump may be built with either below or above grade discharge points. Some typical pumps are shown in Figure 3-12.

The propeller casing of this pump frequently resembles a short length of pipe as compared to special design or construction of the centrifugal pump. Usually the pump casing is equipped with a set of *Diffuser Vanes*. The purpose of these vanes is to reduce the turbulence caused by the action of the impeller and also to direct the flow of water to the discharge pipe.

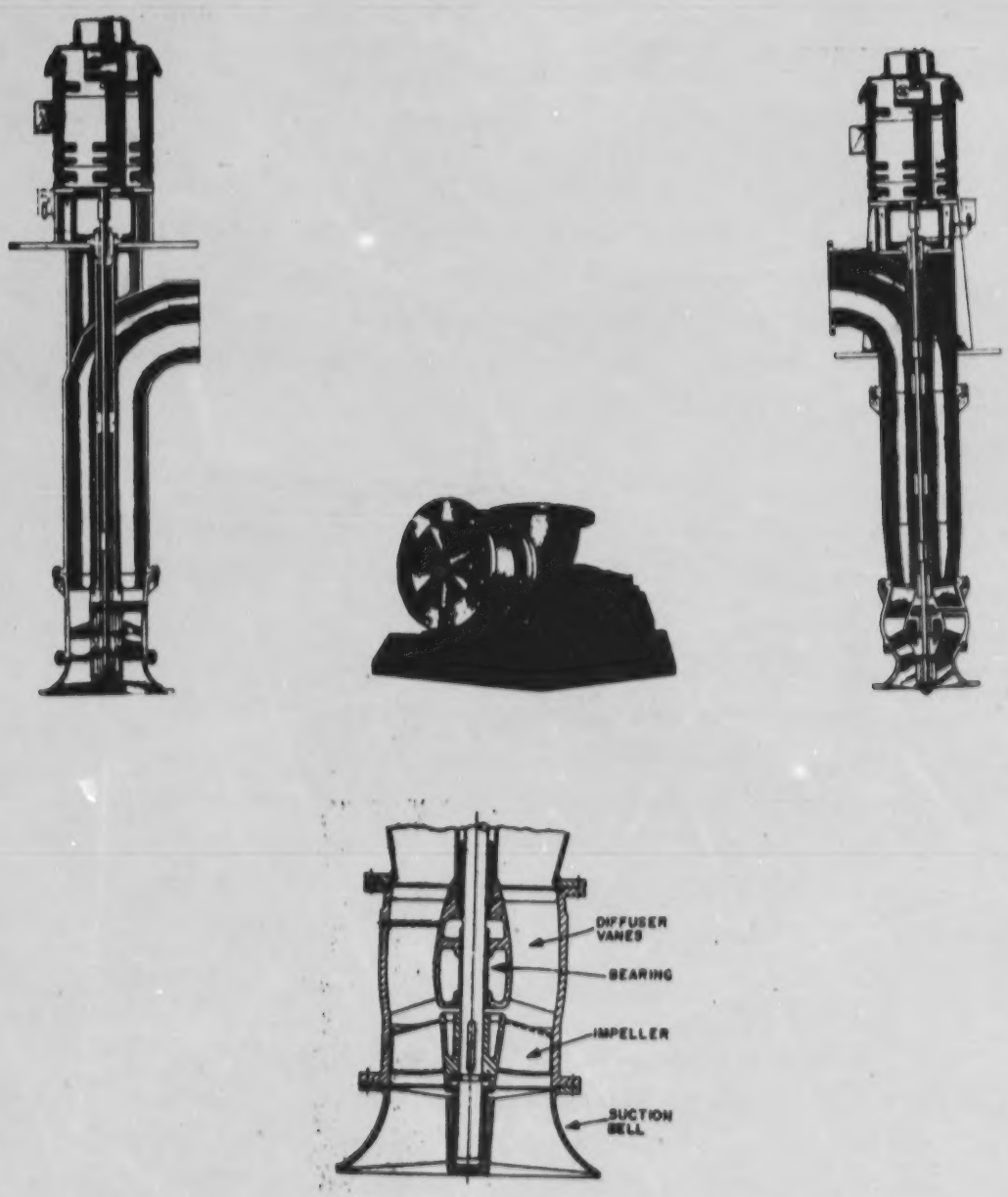


Figure 3-12

Typical Axial-Flow Propeller Pumps

Mixed-Flow Pumps

Although this pump is very similar in design to the axial-flow, the impeller heads are quite different, as illustrated in Figure 3-13.

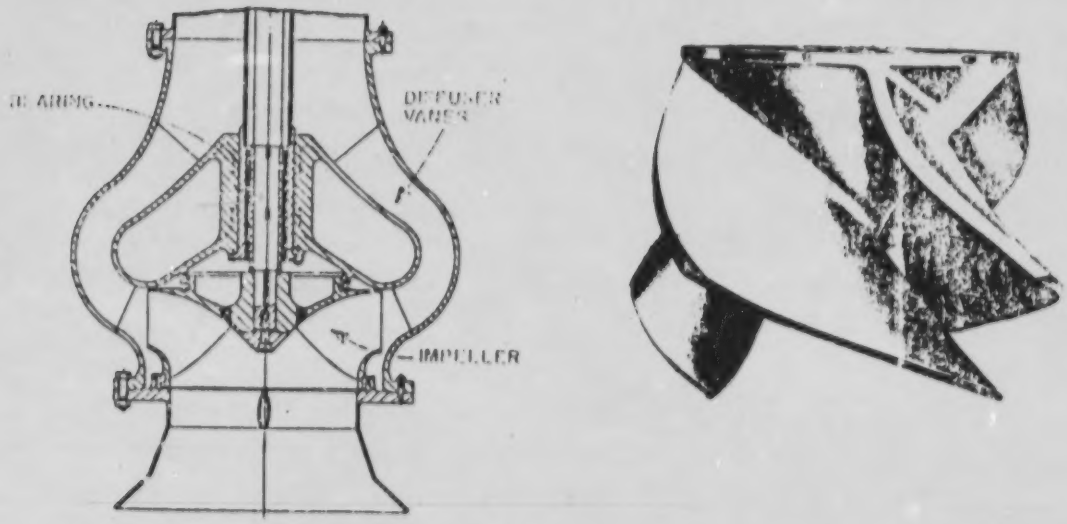


Figure 3-13
Impeller for the Mixed-Flow Pump.

Unlike the axial-flow impellers which move the water in straight lines parallel to the shaft, the mixed-flow impellers give the fluid a swirling or a slight centrifugal motion as it leaves the impeller blades. This design provides the pump with a capability of a slight suction lift. However, these pumps are restricted to operating speeds of above 4200 rpm. Operating at speeds below 4200 rpm decreases the efficiency of the pump considerably.

Although certain mixed-flow pumps resemble a vertically mounted centrifugal pump, it is designed to handle much greater volumes of water.

For installation in wells, the casing of the axial-flow or mixed-flow pump is built slightly smaller than the discharge piping. This is to allow for the removal of the pump for servicing without the necessity of having to dismantle the well piping and the supports. The pump casing is connected to the discharge pipe by a split adapter ring. When this ring is removed, the pump can then be lifted without any difficulty.

The vanes on the mixed-flow impeller are enclosed in a shroud discharging the fluid outwardly much the same as in the centrifugal pump.

With exception of the thrust bearing, the bearings supporting the shafts in axial-flow and the mixed-flow may be of the sleeve, roller or ball type. They can be lubricated by grease, oil or water depending on the application or the pump's design. Depending on the manufacturer's specification, the pump seals can be either mechanical or packing type.

Vertical Turbine Pump

Vertical turbine pumps are often used in municipalities to pump water from deep wells. When necessary, this type of pump can be designed to work under head pressures of 1,000 feet. The size and capacity of the pump is usually restricted by the diameter of the well and the amount of water it is capable of supplying. This pump is usually built up of a number of segments or stages. The number of segments required will depend upon the well-head requirements (Fig. 3-14).

The impeller casing is usually called the pump bowl. The height of the bowl may vary with design of the pump. In some pumps the impellers will be fairly flat, while in others they will be shaped similar to the mixed-flow impeller.

Bearings are normally installed in each casing bowl. This means that in pumps with multiple series each bowl has separate bearings supporting the shaft. Bearings are also located at intermediate points along the drive shaft rising to the motor. In water supply installations, the bearings are lubricated by water being pumped.

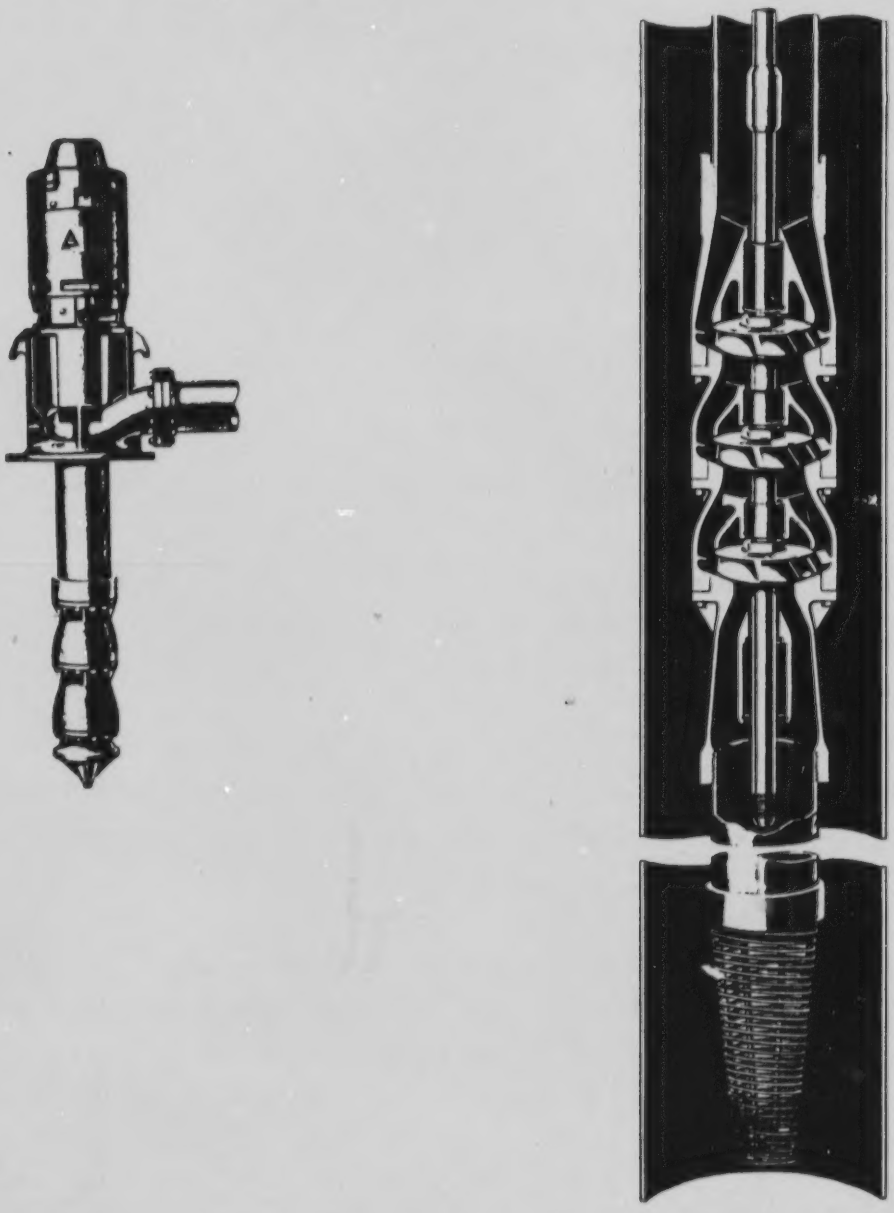


Figure 3-14
Typical Vertical Turbine Pump

POSITIVE DISPLACEMENT PUMPS

ROTARY PUMPS

General

The term Rotary Pump includes a wide variety of pumps designed for handling:

(a) liquids

(b) vapor-liquids

(c) gases.

They are available in sizes from small cooling-water circulating to fairly large units handling viscous products.

Rotary pumps are positive displacement pumps, with relatively steady (non-pulsating) flow. The capacity is approximately proportional to the pump speed. Capacity control of this type of pump may be obtained by varying the speed of the pump or by recirculating a portion of the discharge.

Liquids with a wide range of viscosity can be handled by rotary pumps. They will operate satisfactorily on liquids of high viscosity, where centrifugal pumps will not function.

Rotary pumps are self-priming and can handle a certain amount of vapor or gas together with the liquid pumped. Certain types of these pumps, when properly lubricated, can be used to pump gas or vapor continuously as vacuum pumps.

Types

Most rotary pumps are of three general types:

1. gear pumps
2. vane pumps
3. eccentric-rotor (cane and piston)
4. screw pumps.

These pumps are shown in Figure 3-15. The gear and screw type pumps may be classified as:

(a) internal bearing

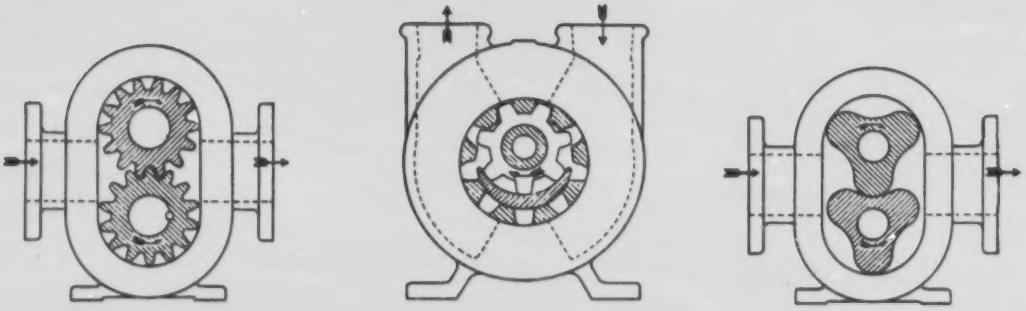
(b) external bearing.

Certain gear and screw pumps are fitted with external timing gears which prevent contact between the pumping rotors.

The internal bearings are lubricated by the product pumped, while the external bearings are lubricated separately in a housing separate from the pump case by stuffing boxes, Figures 3-16(a) and 3-16(b).

If cavitation is to be avoided, rotary pumps handling liquids must have sufficient pressure at the suction end to ensure that they are completely filled with liquid. The suction pressure required depends on pump speed, design and on the viscosity of the material pumped. Rotary pumps will work satisfactorily with low NPSH provided the pump is not operated at an excessive speed. If NPSH available is lower than required, the speed of the pump must be reduced.

When viscous materials are handled, care should be taken in sizing the suction piping to ensure that the required flow rate could be delivered to the pump. If

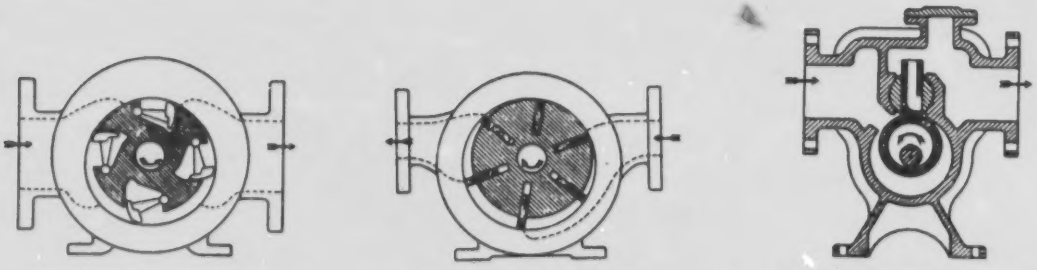


EXTERNAL-GEAR PUMP
A

INTERNAL-GEAR PUMP
B

THREE-LOBE PUMP
C

GEAR PUMPS

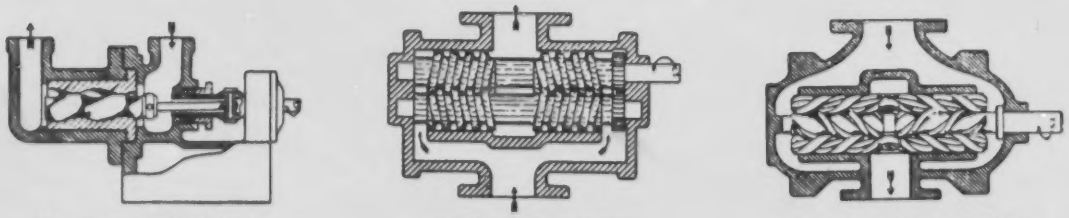


SWINGING-VANE PUMP
D

SLIDING-VANE PUMP
E

CAM-AND-PISTON PUMP
F

ECCENTRIC-ROTOR PUMPS AND VANE PUMPS



SINGLE-SCREW PUMP
G

TWO-SCREW PUMP
H

THREE-SCREW PUMP
I

SCREW PUMPS

Figure 3-15
Common Type Rotary Pumps

NPSH is limiting and the viscosity is increased, the size of the suction passages must be increased or the capacity of the pump must be reduced by reducing the speed of the pump so that friction drop in the suction passages will not prevent the pump from filling completely.

Relief Valves

Since rotary pumps are positive displacement pumps, pressure relief valves are required to protect them from over-pressure. In some designs, a recirculating relief valve is installed as an integral part of the pump. This valve should be inspected periodically to ensure that it is not crusted up and stuck in closed position.

The features of rotary pumps are summarized on page 3-27.

FEATURES OF ROTARY PUMPS

	Gear Pumps	Eccentric-Rotar Pumps and Vane Pumps	Screw Pumps
Frequency of use	Generally least expensive and most frequently used.	Often inexpensive but excessive wear except on clean lubricating stocks may limit application. Frequently used for handling air or gas.	Often only type available in higher pressures for larger capacities. Usually more expensive than other types in smaller capacities and lower pressures. Almost a standard for delivering fuel oil to burners.
Internal Design	Various forms of gears are used: external spur, internal spur, herring-bone, and spiral.	Eccentric rotor or case with vanes or other sealing members. Always has metal-to-metal rubbing, surfaces lubricated by product pumped. Some types have removable liners and vanes which can be replaced when worn.	Meshing screws. Thr rotor of the single-screw pump does not run concentrically but circles around the axis of the stator.
Speeds	Herringbone and spiral gears can be run at standard motor speeds of 1150 and 1750 rpm in smaller pump sizes. Larger sizes and other gear types ordinarily require lower operating speeds.	Usually slow speed requiring geared drivers. Small capacity units sometimes operate to 1750 rpm.	In single-screw and two-screw pumps, speeds up to 1750 rpm are obtainable in smaller sizes and for some services. Lower operating speeds are usually required. In three-screw pumps motor speeds of 1750 or 3550 rpm are usually acceptable, and, for occasional services, speeds to 5000 rpm are satisfactory.
Bearing Location and Lubrication	Either internal (lubricated by product pumped) or external (separate housing for separate lubrication). See Figures 3-2 and 3-3.	All bearings and rubbing surfaces internal (lubricated by product pumped).	Either internal or external bearings for two-screw pumps. External bearings on drive shaft of single-screw pump but there is rubbing contact between stator and rotor. Internal only for three-screw pumps.
Timing Gears (to prevent contact between rotors)	Used in external-bearing designs or when special gear teeth shapes do not allow one pumping gear to drive the other.	None	Required for two-screw pumps. Not available on single- or three-screw pumps.
Working Pressures	Normally up to about 400 psi with internal bearings. Special design to about 2000 psi for filtered lubricating liquids. For external bearings pressures to 300 psi are obtainable in small sizes, with 50 to 150 psi for larger sizes.	Varies with design and size. Pressures to 1000 psi are obtainable but most common designs are for 75 to 200 psi.	Single-screw pumps to 200 psi. Two-screw pumps to 400 psi. Three-screw pumps to 1500 psi.

RECIPROCATING PUMPS

Reciprocating pumps are positive displacement pumps. Within the limitations of pump construction, the maximum pressure developed is limited only by the torque of the driver for crank-driven pumps. The capacity can be controlled by varying the speed of the driver and adaptable speed reduction gears.

The flow of liquid from this type of pump is pulsating, varying both in flow rate and pressure. One of its principal applications in water and wastewater treatment is for handling materials which are highly viscous or contain heavier solids. A cross-section of the pump is shown in Figure 3-17.

Types

Following are a few of the most common means by which reciprocating pumps are classified:

1. Type of Drive
   (a) Direct-acting, steam-driven
   (b) Crank-driven (often called "power" pumps) (Figure 3-17)

2. Cylinder Orientation
   (a) Horizontal
   (b) Vertical

3. Liquid-End Arrangement
   (a) Plunger-type (outside packing),
   (b) Piston-type (inside piston rings or packing on the piston)

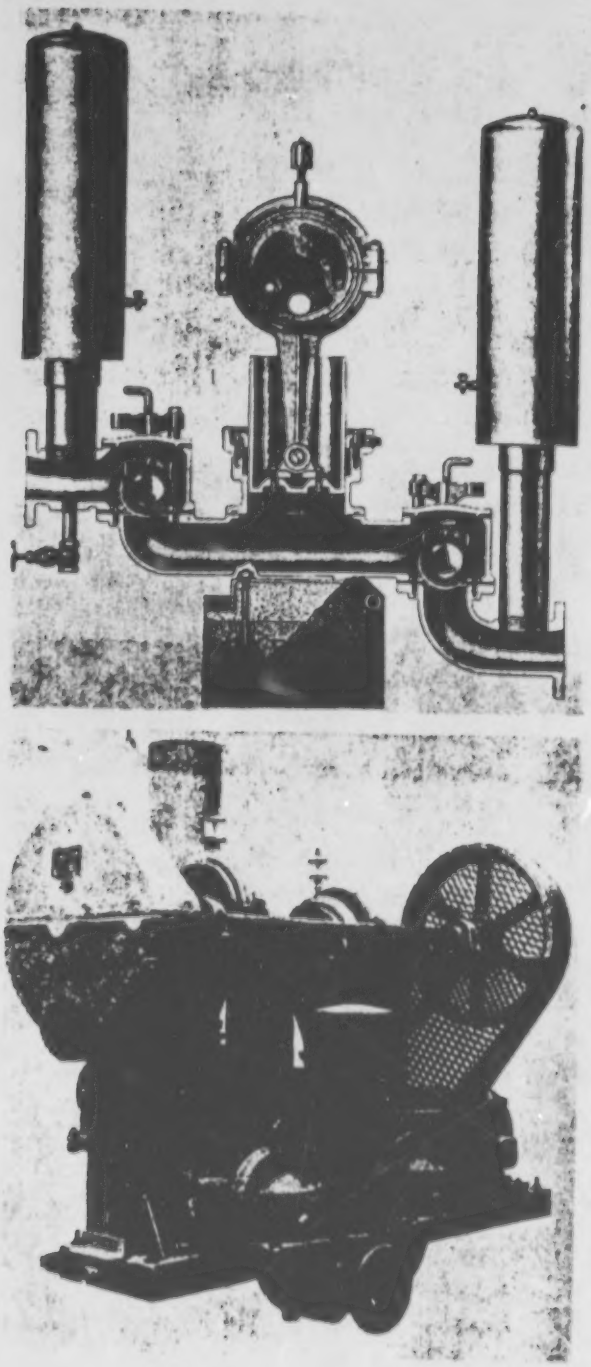


Figure 3-17
Typical Reciprocating Pumps

4. Valves and Cylinders (classified by arrangement and design)

(a) Valve-plate
(b) Pot valve
(c) Turret-top,
(d) Close-clearance,
(e) Forged-steel, integral valve.

5. Number of Pistons or Plungers

(a) Simplex,
(b) Duplex,
(c) Triplex,
(d) Quintuplex, etc.

6. Type of Action

(a) Single-acting (delivers on either forward or backward stroke, not both),
(b) Double-acting (delivers on both forward and backward strokes).

Sizes and Size Designation

The sizes of reciprocating pumps vary from small proportioning pumps with very short adjustable strokes to large high-pressure pipe line pumps with strokes of 36 inches or more.

The size of a simple reciprocating steam pump is expressed in inches by three figures as follows: diameter of steam cylinder x diameter of liquid cylinder x length of stroke (e.g. 6 x 5 x 6). Note that this size designation does not tell whether the pump is simplex or duplex, valve-plate or side-pot, close-clearance or not, etc.

The size of crank-driven reciprocating pumps is usually expressed in inches with two numbers as follows: diameter of the liquid piston x length of stroke (e.g. 3 x 10).

Cylinder Liners

Most reciprocating pumps are equipped with cylinder liners. There are two general types - replaceable and removable. Replaceable liners are press-fit and must be removed with a cutting tool and replaced in a hydraulic press. Removable liners are usually held in position by bolts or screws and can ordinarily be removed with hand tools. Removable liners are preferred.

Valve Arrangements

The most common valve arrangements for the liquid end of reciprocating pumps and their approximate pressure limitations are:

1. Valve-plate construction provides a single cover for all the suction and discharge valves. This construction is not commonly available for discharge pressure above about 250 psi in cast iron.

2. Pot-valve construction provides each suction and discharge valve with a separate chamber usually cast on the side or top of the cylinder. Each "pot" has a separate bolted cover and can be designed for high pressure.

3. Integral-valve construction provides a separate chamber for each suction and discharge valve machined in the cylinder block. This is the usual construction for forged steel liquid ends and is suitable for the highest pressures for which reciprocating pumps are designed.

Valve Types

The type of valve for a given service is usually determined by the pump manufacturer. Some of the most common types of valves are:

1. A disc-type valve is simply a flat plate which closes over the valve port, usually under spring pressure. Disc-type valves of special design are also used on high-pressure, high-speed reciprocating pumps for pipe line and similar services. These valves have operated satisfactorily at pressures up to 2,000 psi.

2. Wing-guided-type valves have an extension below the seat of the valve to provide a guide which keeps the valve in line as it rises and assures its seating properly. Wing-guided valves are ordinarily offered for pressures above 350 psi and are applied up to the highest pressures for which reciprocating pumps are designed.

3. Ball-type valves are round balls which usually seat themselves in a different position each time they open and close, thus preventing continued wear on any one spot. Ordinarily, ball valves or semi-ball valves of the "Rollo" type offer less resistance to flow and so are recommended for pumps handling highly viscous materials. They are, however, comparatively heavy and therefore not well adapted to high-speed service.

Length of Stroke

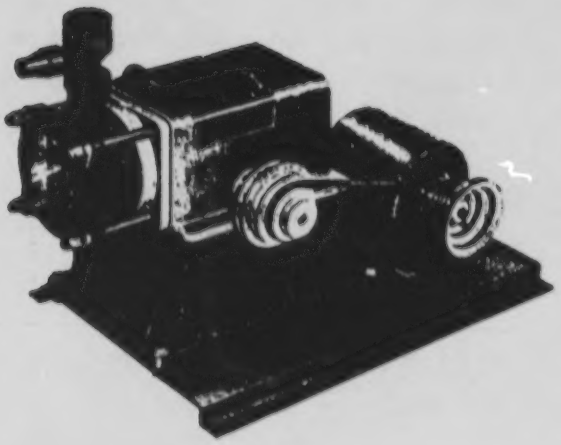
Other factors being equal, a long stroke with a piston or plunger of comparatively small diameter is usually more satisfactory than a shorter stroke with a larger piston or plunger diameter. The reduced shaft or plunger size gives longer packing life and the efficiency is usually improved as the length of the stroke is increased. However, the very high speed pumps that have recently come into fairly wide use have a short stroke. Their frames, bearings, and shafts are very heavy and rigid.

Controlled Volume Pumps

In water and wastewater operation, a requirement frequently arises for a relatively small-capacity, high-discharge-pressure pump to handle chemicals at controllable rates. Generally controlled-volume reciprocating pumps, often called proportioning pumps, are most satisfactory. If the chemicals handled are corrosive to iron or steel, special materials must be used.

Controlled-volume pumps are designed for ready adjustment of the flow rate. They could deliver the set flow against varying discharge pressures. These pumps are usually reciprocating plunger pumps of the single-acting, crank-driven type. Diaphragm-type, controlled-volume pumps are also available and eliminate the stuffing box that may be a source of trouble in the plunger-type pumps. (Figure 3-18).

These pumps are manufactured to handle capacities as low as a few cubic centimeters an hour up to about 25 or 30 gpm. In the lower capacities differential pressures up to 20,000 psi are available. Typical services include:



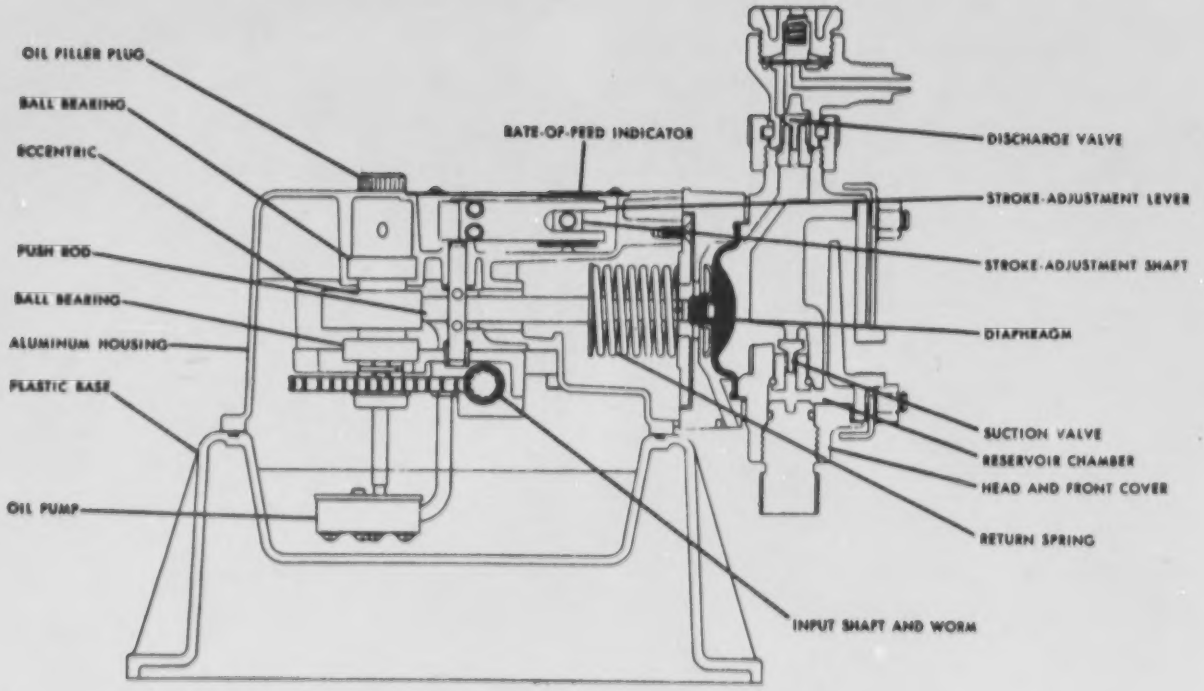


Figure 3-18

Diaphragm-type Chemical Feed Pump

(a) Injection of acid or other chemicals for water treating.

(b) Controlled injection of chemicals into process streams.

The flow rate in these pumps is controlled by varying either the stroke length or the pump speed. Where necessary, these pumps can be fitted with controls permitting flow adjustments while the pump is running. This adjustment can be automatically controlled when process conditions require.

Piston Pumps vs. Plunger Pumps

Piston pumps are almost invariably cheaper than plunger or outside-packed pumps. The design of plunger pumps, however, allows injection of an external lubricant into the stuffing box if needed to prolong packing life. Further, leakage past the packing can be observed and the packing adjusted as required. None of this is possible with the internally packed piston-type pumps. Piston pumps, however, with metal piston rings for packing are available in crank-driven types for pressures up to 1,500 psi.

When suction pressure is less than atmospheric, a piston pump should ordinarily be selected since the outside-packed plunger pump generally permits greater leakage of air and the design of the liquid passages is not suited to clearing themselves of accumulations of air.

Applications of Reciprocating Pumps

In recent years reciprocating pumps have been replaced in many applications by centrifugal pumps, largely because of cost. Reciprocating pumps, however, possess advantages of flexibility of head and capacity with nearly uniform efficiency over a wide range of conditions. Thus, for certain services, they are a better selection than centrifugals. In general, they are preferred for small capacity high-pressure services.

While small reciprocating pumps are fairly competitive with centrifugal pumps, in large sizes (particularly over 200 gpm capacity) they are apt to be more expensive than other types.

For many services, the operating costs of motor-driven or turbine-driven centrifugal pumps will be less than for reciprocating pumps. Maintenance costs for reciprocating pumps will usually exceed those of a centrifugal pump because of the valves, the many moving parts, and the sliding contacts in the reciprocating pump.

Pulsating flow sometimes limits the application of a reciprocating pumps. It will seldom be found, however, that pulsating flow alone is a controlling factor for services where reciprocating pumps are otherwise the best selection. The effects of *pulsation could be corrected by the use of pulsation dampeners* in certain installations. Further, in some cases pulsation effects can be minimized by selection of adequate line sizes since the magnitude of the pressure variation is inversely proportioned to the flow area of the pipe. This is particularly important for low speed pumps discharging into relatively short lines.

Pulsating flow may introduce some problems in the application of automatic control and flow measurement, but usually this can be taken care of without undue difficulty or cost.

Some usually good applications are:

1. Low capacity with relatively high differential pressure or moderate capacity with very high differential pressure.

2. Relatively high viscosity. Reciprocating pumps can economically handle stocks up to about 8,000 SSU (both viscosities at flowing temperature). However efficiency of a centrifugal pump drops rapidly with increasing viscosity.

3. Relatively constant capacity with widely varying discharge pressures. Crank-driven pumps are particularly suited to this application.

4. Highly variable capacity with either constant or varying discharge pressure.

Some usually poor applications for reciprocating pumps are:

1. Whenever pulsating flow is in fact objectionable. An example of such a service is the feed of fuel to boilers. Ordinarily, rotary pumps are preferred for this service because of their smooth discharge pressure.

2. Medium capacity and medium differential pressure with low viscosity. Centrifugal pumps will ordinarily be more economical. Examples of such services are water or petroleum products in the range above about 100 gpm with differential pressures up to about 300 psi.

3. High capacity. For capacities beyond about 200 gpm, reciprocating pumps are rarely the proper selection regardless of the discharge pressure. In this range the size of reciprocating pumps becomes so large that they are more expensive than centrifugal pumps.

SUBJECT:

PUMP OPERATION

TOPIC: 4

PUMP CONTROLS

OBJECTIVES:

Trainee will be able to:

1. Name the various types of pump controls commonly used in pumping operations.

2. Recall the functions the automatic pump controls may provide in various operations.

3. Identify the type of pump control associated with a specific pumping operation -

   (a) Constant speed drives
   (b) Variable speed drives.

4. Name the level sensing controls and describe their applications.

5. Name the pressure or vacuum sensors and describe their applications.

6. Identify the various functions performed by the auxiliary controls.

PUMP CONTROLS

GENERAL

In water and wastewater systems there are three categories of pumping equipment. These are:-

(a) Water Pumps
(b) Sewage Pumps
(c) Process Pumps

Most of these pumps are driven by electric motors either directly or via variable speed couplings; furthermore most variable flow control is provided by variable speed pump operation. For the sake of clarity this class of equipment only is covered in this section. Pump control in this application covers flow control by starting, stopping or varying the speed of the pump either manually or automatically.

Manual pump controls involve the starting and stopping of the pump by manual switch, push button or control selector. Manual variable speed control requires a manual speed rheostat or cone pulley adjuster. These controls are relatively easy to provide and are sometimes added to an automatic system for emergency use and to assist in fault finding.

Automatic pump controls are much more complex since the pumps may have to meet one or more of the following:-

(a) operate within prescribed limits such as levels in a well or pressure limits in a pipe;

(b) provide automatic transfer to the standby pump in the event of failure of the lead pump;

(c) provide a variable flow to suit the requirements of a treatment plant or prevent water hammer;

(d) operate to a programme which might involve many functions associated with the pumps such as a backwash filter.

All of these functions require monitoring to determine when to operate the pumps and to prevent incorrect operation also to protect the equipment from damage. The monitors or sensors are the "eyes" of the equipment which signal the controls to operate. If a sensor or associated control fails then the automatic operation of the pump fails. An understanding of the sensors and associated controls will help you to understand the automatic operation of the pumping system.

PUMP DRIVES

There are two categories of pumping, constant flow and variable flow, which affect the selection of the pump drive. Constant flow pumps are used where a batch process is required or where a difference in liquid level or pressure is acceptable. It is good practice to ensure that the pumps would not cycle (start, pump, stop) more than 6 times per hours. Variable flow pumps are used where the flow is required to follow a variable input flow, called pacing, or to maintain close limits of liquid level or pressure. Variable flow is usually obtained by a variable speed pump.

Constant Speed Drives

The constant speed pump is driven by a constant speed, squirrel cage, electric motor and is operated in an on-off manner. This is the most economical, rugged and reliable form of pumping and is used whenever constant flow pumping is acceptable.

Variable Speed Drives

Variable speed pumps may be driven directly by variable speed motors. The motors may be powered by:

- Direct current (DC) as in the case of DC motors driving small chemical metering pumps.

- AC, variable voltage as in the case of special squirrel cage motors (Design D).

- AC, variable frequency as in the case of of squirrel cage motors.

- Alternating current (AC), constant voltage, as in the case of wound rotor motors.

A wound rotor motor may have its speed regulated by varying the electrical resistance connected to the rotor or secondary of the motor by:-

- Liquid rheostat e.g. "Flo-Matcher".
- Dry type rheostat such as resistance grids.
- Reactor or a combination of reactors and resistances.
- Solid state power feedback.

A variable speed pump may also be driven by a constant speed motor through a variable speed coupling. This coupling may be:-

- Electrical eddy current coupling.
- Cone pulley sheave drive.
- Hydraulic slip coupling.
- Hydraulic gear pump coupling.

The selection of a variable speed drive for a particular application can depend on capital cost, operating cost, maintenance cost, dependability and the performance required. There is no precise guide and often depends on the designer's discretion although certain applications favour certain types of drive.

SENSING CONTROLS

These controls monitor the required part of the system e.g. level in the well and initiate the auxiliary controls to start, stop and, where required, to regulate the speed of the pump motor. The controls may be:

1. Level sensors such as float switches, bubbler regulators, sonic detectors, conductance and capacitance probes.

2. Pressure or vacuum sensors such as a diaphram switch.

Float Switches

These are the most common sensors used for turning pumps on and off since they are simple and rugged. However, their use is limited to constant speed or multi-speed motors. They cannot be used with variable speed drives.

A float comprises a mercury switch, inside an insulating body typically in the shape of a pear, connected to a cable. The pear is suspended by the cable from a hanger assembly and will assume a different position when floating in the liquid compared with hanging in free air. The floats are arranged at different levels in the well to operate one or more pumps, e.g. (a) stop all pumps (b) start lead pump (c) start lag pump (d) operate high level alarm. The mercury switch in the float may have normally open contacts or normally closed contacts alternatively both and are applied according

to the desired function.

Bubbler Regulators

These are applied quite frequently and can be used with constant speed, multi-speed or variable speed drives. The control is very flexible since the liquid operating levels can be adjusted quite readily and a liquid level indicator can be incorporated. However, more equipment is required such as a compressor, pressure switches, pressure reducing and needle valves, also an air flow indicator.

In a bubbler system a low pressure air supply is allowed to escape from a sensing pipe in the well. The back pressure on the air supply will vary with the level of the liquid in the well. Sensitive air pressure switches respond to the change in air pressure caused by a change in level in the well. A pressure switch may be of the type to turn on or turn off the pump motor, or do both functions alternatively, or a controller of a type to regulate the speed of the motor or coupling.

Sonic (Ultrasonic) Detectors, Capacitance & Conductance Probes

These sensors are in a number of more recent installations. The conductance probe is fairly common in a clean location such as a clear well of a water pumping station with constant speed pumps. This is a simple device and requires little service.

Sonic (ultrasonic) detectors and capacitance probes can be used for variable speed as well as constant speed pumps. These sensors are more complex and consequently require more sophisticated service than is usually available in many localities. However, advances in design are reducing the probability of failure or drift in performance.

So far the float or bubbler sensors appear to be very suited to the arduous application of a sewage wet well as regards simplicity and dependability.

Pressure and Vacuum Switches and Controllers

These sensors operate in a similar manner to the bubbler pressure switches and are used in water pumping stations. The diaphrams of these switches can operate an electrical on-off switch or operate through a transducer to control a variable speed drive.

AUXILIARY CONTROLS

A pump control panel contains a number of auxiliary controls which work in conjunction with the pump starters. These controls play an important part in the:-

(a) Transmission of the sensing signal to control the operation of the pumps.

(b) Interlocking of the pumps to prevent incorrect pump operation.

(c) Delay of the pump operation to suit the power supply or hydraulic load requirements.

(d) Sequence timing of the pumps or auxiliary equipment.

(e) Overload protection of the motors.

Manual Controls

These controls are auxiliary devices located on the control panel, starter panel or near the machine. They

include one or more of the following:-

1. On-Off Push Buttons (momentary contacts)
2. On-Off Push Buttons (maintained contacts)
3. Hand-Off-Automatic ("H.O.A") Selector Switch
4. Duty Pump Selector Switch
5. Programme Selector Switch
6. Manual Speed Rheostat
7. Overload Reset Push-Buttons
8. Manual Disconnect Switch
9. Manual Motor Starter

All these controls play an important role in the operation of the pumps. They must be in the correct position for satisfactory operation. It is embarrassing when it is found that incorrect operation of the pumps has been caused by the wrong position of a selector switch.

Auxiliary Relays

These are usually intermediate relays to provide a sequence or multiple function, e.g. operation a large starter, operate an alarm, etc.

Time Delay Relays

These provide the necessary time intervals in the operation of a reduced voltage starter on the sequence starting of a number of pumps.

Overload Relays

These are thermal-trip units with the elements in the main motor current circuits. Alternatively, heat sensors may be provided in the motor winding which operate through a protection unit in the control panel.

Time Controls

These are used where a process such as a filter backwash involves a considerable number of component operations. A convenient analogy to this would be the time control in an automatic washing machine. In addition to the time control, a backwash filter would have sensors for backwash sampling and to measure the head across the filters.

Transducers

These are converters which change analogue signals (variable) of one form into another form, e.g. pressure in a bubbler system into control current for a variable speed drive. The control current is usually compared with a reference to vary the pumping rate according to the wet-well level or a constant pressure in the water system.

This device is part of a control module which varies the speed of the pump either through the variable speed coupling or directly on the motor. The type of equipment and method of operation is quite specialized and would be beyond the scope of this topic.

PUMP MOTOR STARTERS

The pump starter is the main power control device before the pump motor and is a vital link in the operation of a pump. They are installed singly or in groups such as a 4 plex or a motor-control centre.

The type of starter will depend on:-

1. The size of the pump motor.
2. The voltage and capacity of the electrical power supply.
3. The method of pumping operation.

Many pump motors from say 1/2 hp up to and beyond 200 hp operate from a supply of 600 volts 3 phase 60 Hz. Motors larger than say 250 hp operate on a supply of 4160 volts 3 phase 60 Hz or similar high voltage. Single phase motors and 230 volt 3 phase motors are sometimes used say below 10 hp where 600 volt 3 phase power is not available or because of cost.

Full Voltage Starters (Squirrel Cage Motors)

This is the most common method of starting a motor because it is simple, rugged and relatively inexpensive. It is used wherever the electrical power supply will accept this type of starter.

The starter unit usually comprises a 3-pole contactor (for 3 phase supply) together with auxiliary controls and a combination breaker or switch-fuse. The starter is metal enclosed with a hinged front cover. The cover is mechanically interlocked to ensure that the combination breaker or switch-fuse is open before the contactor, etc. can be serviced. The cover is usually equipped with on-off push bottons or H-O-A selector switch, on-light and overload reset buttons.

Reduced Voltage Starters (Squirrel Cage Motors)

These starters are used where the power supply cannot accept the heavy starting demand of full voltage starting whether from the PUC supply or from standby generators.

There are several types of reduced voltage starters:-

1. Auto Transformer
2. Primary Resistor
3. Part Winding
4. Star Delta.

Each type has its own advantages as regards price, provision of a smooth start and demand on the power supply. When pumps are operated with a standby generator a very flexible and compatible starter is the auto transformer closed-transition starter.

The starters contain more equipment than full voltage starters such as two or more contactors, auxiliary relays also an auto transformer or primary resistors. Consequently, they are much more expensive.

Wound Rotor Motor Starters

The starter of a wound rotor motor behaves like a reduced voltage starter since the demand on the power supply is the same. It consists of a full-voltage starter similar to a squirrel cage motor for the primary of the motor. In addition, a secondary controller is provided to regulate the speed of the motor as well as give a "smooth" start. As previously mentioned, the secondary controller can take the form of a liquid rheostat, dry type resistances or special solid state circuits.

Liquid rheostats, such as "Flow-Matchers" are relatively simple and inexpensive to provide automatic control of the variable speed feature. The external resistance applied to the motor secondary is provided by electrodes immersed in a bath of electrolyte. The level in the bath rises or falls in unison with the level of the liquid in the wet well which varies the secondary resistance and so varies the speed of the motor. The main limitation with this equipment is the excessive maintenance required on the electrolyte bath which has caused the Ministry of the Environment to prefer other types of variable flow control.

A more recent development is the solid-state power recovery form of variable speed drive. This unit varies the resistance applied to the motor rotor by solid-state devices and feeds the energy, normally lost in heat, back into the power supply. Consequently, the power consumed by this type of variable speed drive is much less than the "slip loss" types. This drive is now receiving more attention due to increased power costs.

UNDERSTANDING PUMP CONTROLS

Actual wiring and schematic diagrams are of particular interest to designers and maintenance technicians but they are not readily understood by operators. A control block diagram appears to be too general and a full description of the control sequence can become too mind boggling for the operator to understand the controls.

The average operator will make a valiant attempt to correct any operating problems encountered, but, not being an electrician, he may cause further problems. Consequently, the electricians called to the scene of a problem may have the original problem as well as the new one introduced by the operator's adjustments. In a typical trouble call, the maintenance electrician arrives at the scene with the basic electrical skills. He can determine whether he has the proper voltage levels, the proper relay or solid state switching operation, check circuit continuity, and perform the other fundamental troubleshooting required. However, in the normal case, the unknown factor is his familiarity with the specific piece of equipment. He may have reasonable familiarity with the process but on the other hand, if the equipment has been designed properly and he has not had to enter the cabinet for a period of months, he needs a quick refresher to review the operation of this particular piece of equipment. This is also true if he's operating from a central shop and may not have seen the equipment for a protracted period of time. What is required is an effective communication tool between the operator and the maintenance man in describing what the operator was attempting to do, what he saw happen, and in what step of the process the failure was noted or what conditions are causing the malfunction.

For a number of years, designers have used the "logic diagram" as the universal language for communicating design intent between members of an engineering team regardless of the individual's specialty. It serves this purpose because of its simplicity, but it does not replace the actual or schematic circuit diagrams. It has been found that the logic diagram can also help the operator to know what he is doing, why he is doing it and where to locate the trouble area when anything goes wrong. The logic diagram will also guide the technician in confirming the operators diagnosis and when assisted by the actual or schematic circuit diagrams he can locate the faulty component.

It is not intended that the Ministry prepare logic diagrams of pumping station controls existing installations. As this is a relatively new tool and its application still questioned, some experience is needed before asking the Consulting Engineers to provide additional diagrams on new installations. It is thought that based on his knowledge of the operation of the controls (and with assistance from the maintenance technicians) the operator can himself prepare logic diagrams and determine their usefulness in a particular installation.

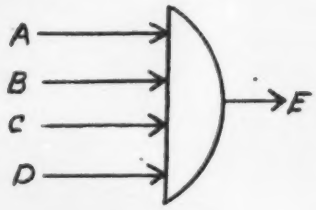
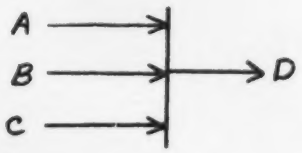
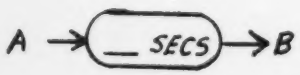
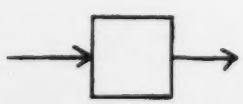
The following brief discussion is designed to introduce the readers to logic diagrams, with a view to encouraging them to apply logic diagrams in their plants as a trouble-shooting aid.

As illustrated in Figure 4-1, a logic diagram employs four symbols to describe functions. Any function that cannot be covered by these symbols can be described by a written notation in a square block.

Figure 4-2 is a schematic for two pumps and float switches. Note the apparent complexity of the diagram. It is obvious that anyone other than an electrician would have difficulty in translating them. Figure 4-3 is a logic diagram for the same controls. If pump does NOT run, it is readily apparent to the operator what he should check to determine the trouble.

Figure 4-4 is an example of logic diagram for a travelling water screen. Figure 4-5 is a logic diagram with hydraulic analogy showing various gate valves which must be "on" before the field receives water.

Appendix 1 is an extract of a paper on logic diagrams which further clarifies the subject.

FUNCTION	SYMBOL	HOW IT WORKS
AND		ALL INPUTS MUST BE PRESENT ie. "A" AND "B" AND "C" AND "D" TO OBTAIN OUTPUT AT "E"
OR		ANY INPUT PRESENT ie "A" OR "B" OR "C" (OR ANY COMBINATION) CAUSES AN OUTPUT AT "D"
NOT		THE STATED INPUT NOT APPLIED AT "A" GIVES AN OUTPUT AT "B" AND VICE VERSA.
TIME DELAY		AN INPUT APPLIED AT "A" IS DELAYED BY THE TIME SHOWN BEFORE APPEARING AT "B"
MISC		ANY FUNCTION NOT INCLUDED IN THE ABOVE MAY BE APPROPRIATELY LABELLED IN A RECTANGLE

NOTE : "INPUTS" AND "OUTPUTS" REFER TO ANY EVENT, ACTION OR CONDITION THAT CAN EXIST OR OCCUR. THEY MAY TAKE THE FORM OF ELECTRICAL, MECHANICAL, HYDRAULIC OR OTHER PHYSICAL CONDITION.

Figure 4-1 CONTROL LOGIC DIAGRAM FUNCTIONS AND SYMBOLS

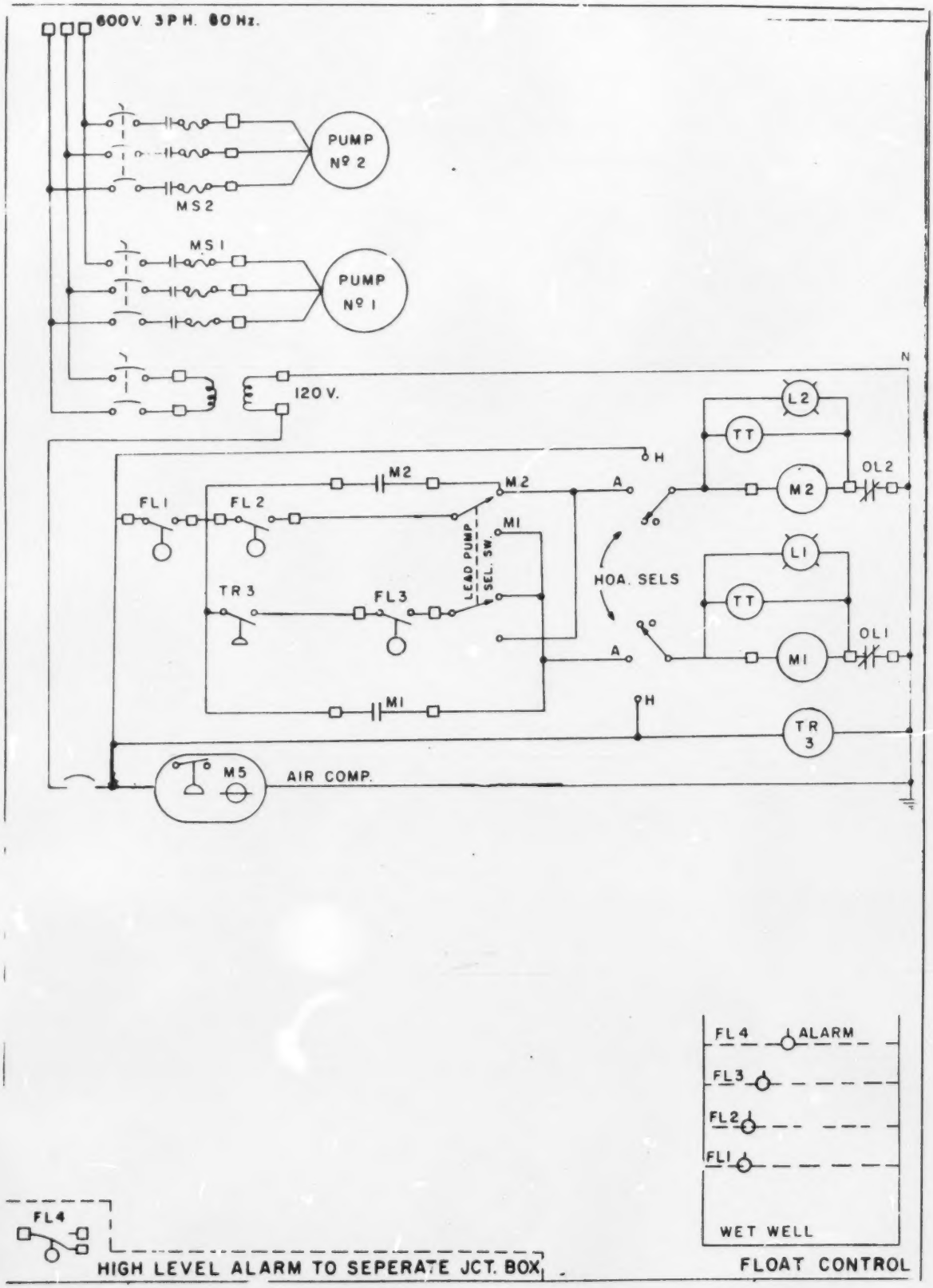


Figure 4-2 CONTROL DIAGRAM SCHEMATIC
TWO PUMPS AND FLOAT SWITCHES

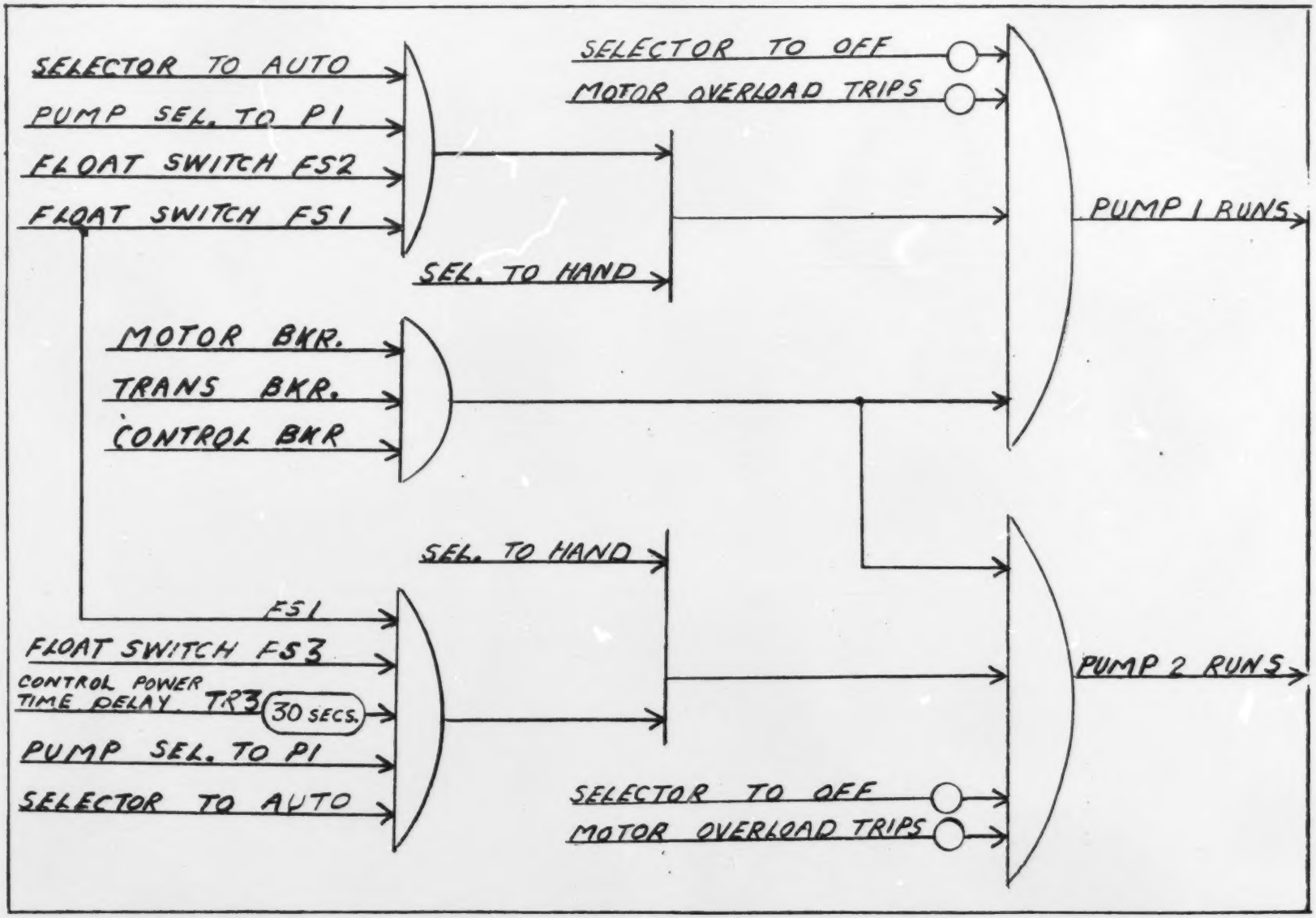


Figure 4-3 LOGIC DIAGRAM TWO PUMPS AND FLOAT SWITCHES

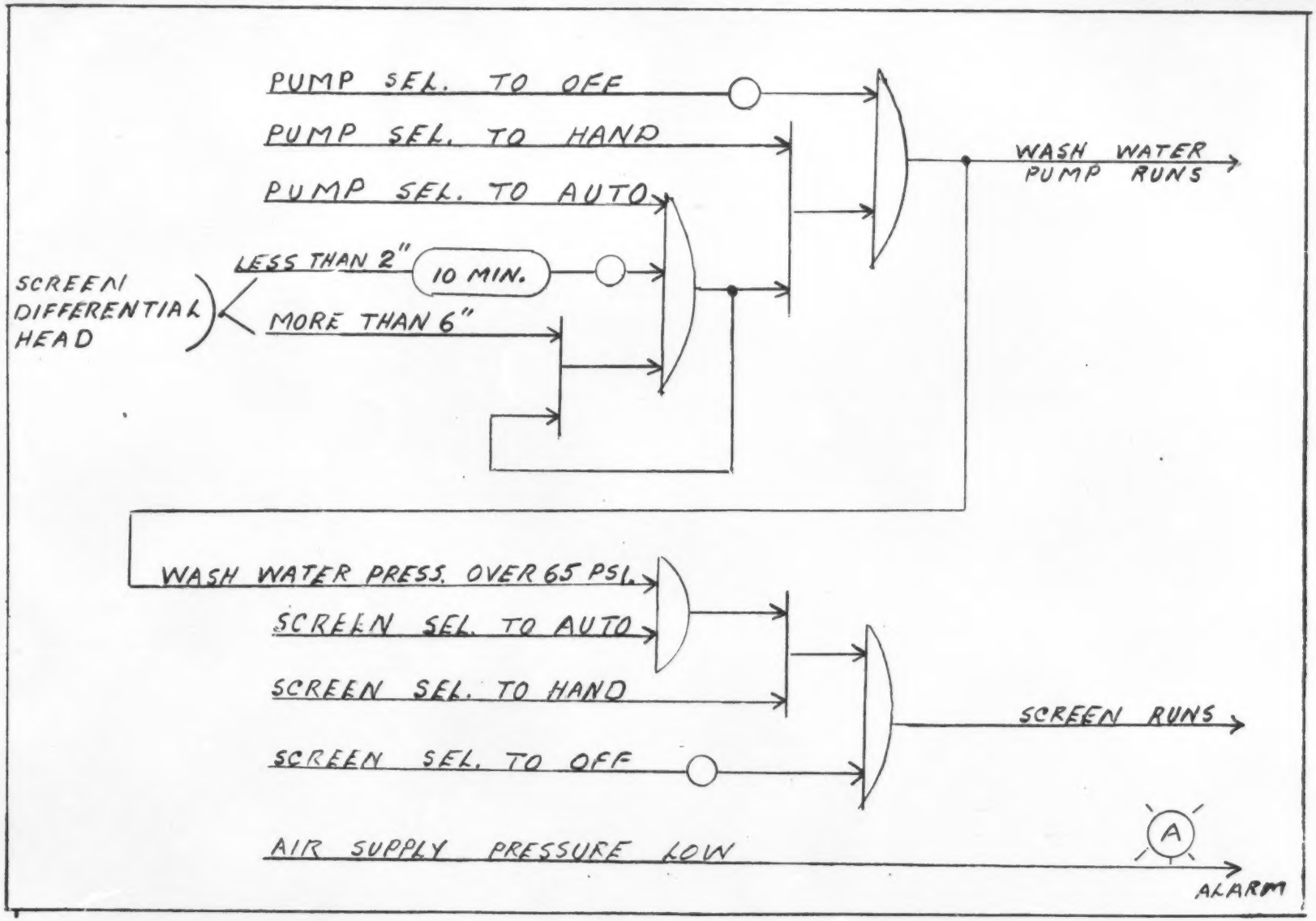


Figure 4-4 LOGIC DIAGRAM TRAVELLING WATER SCREEN

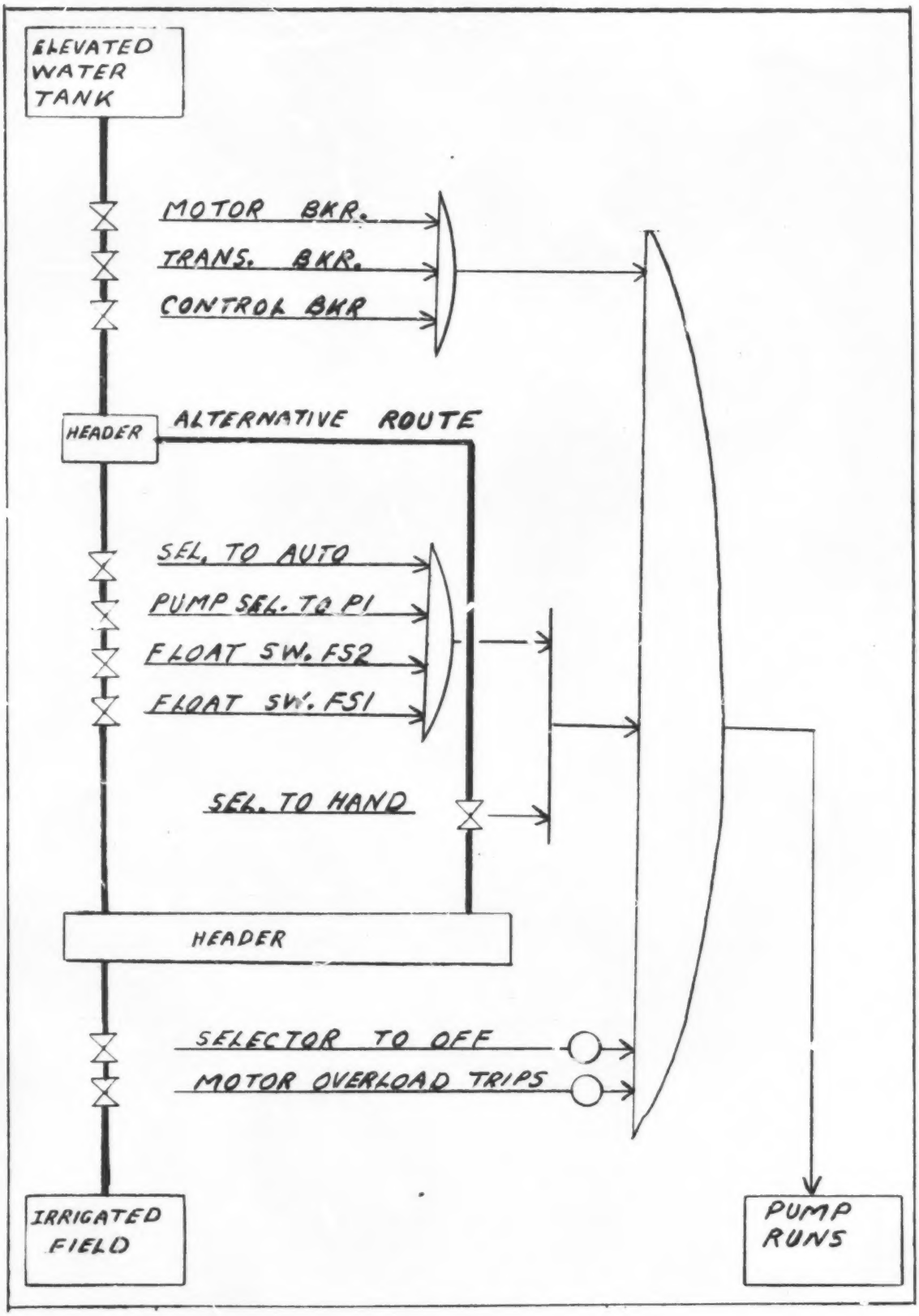


Figure 4-5 LOGIC DIAGRAM WITH HYDRAULIC ANALOGY

ABSTRACT

The Use of Logic Diagrams as a Design and Troubleshooting Tool

To assist you in this subject the following is an extract of a paper prepared by Edward Dacey of the Procter and Gamble Company, Cincinnati, Ohio to the IEEE. This extract is of particular interest to plant operators and the data etc., has been adjusted to Canadian conditions.

"Abstract"

The logic diagram was first used as a design tool. It proved tremendously successful because it provided a universal language for communicating design intent between members of an engineering team, whether their prime responsibility be in mechanical, electrical, instrument, or production engineering. With some modifications and additions, the logic diagram has been found to be a very effective tool for troubleshooting both process and packing line equipment. Again, the universal appeal of the logic diagram has enabled improved communications between the operating and maintenance personnel to localize the malfunction on the logic diagram. References guide the electrician to the specific area of the elementary diagram that describes the circuit operation. From this point, his normal troubleshooting techniques should enable him to rapidly isolate the malfunction and affect speedy repair.

"Extract of Paper"

What is a logic diagram? Well, simply stated, a logic diagram is a means of communicating that employs symbols. At the time that we recognized the usefulness of the logic diagram, there were no universally accepted symbols. We, therefore, chose the following four symbols as the basis for logic diagrams rather than try to take care of all eventualities with symbols. Personnel preparing logic diagrams were asked to use a written notation to describe any function that could not be adequately covered with these

four symbols. The symbols selected as shown on Figure 1 are the "and, the "or", the "not", and the "time delay". Binary logic is employed with these symbols. If a condition exists or is satisfied than that condition assumes a value of "1". If it is not, it is classed as a "0".

Typical examples of the logic diagram for basic electrical systems are as follows. Figure 2 is a motor start-stop circuit. Figure 3 shows two interlocked motors. Figure 4 is a self-lubricated pump. In the case of Figure 4, this is the logic that would be presented by our Electrical Production Engineering personnel after it had been developed from a sketch. The original sketch might look like Figure 5, but it would still convey the meaning. Figure 6 shows the logic for part of a packing line. From the logic diagram as presented, the elementary diagram is then readily developed to accomplish the desired function. Figure 7 shows one method of accomplishing the interlock desired between two motors.

Once the basic format of the logic diagram had been developed, it became apparent that with slight additions the logic diagram could readily convey signal information. A pilot light and the actual colour of the pilot light desired is shown in Figure 8. The addition of an identification block adjacent to the components is an easy way to identify the physical location of the components whether it be in a control panel, motor control centre, or other location. This block is designated panel 501 in Figure 8.

With the success of the logic diagram as a design tool established, attention was focused on the use of this tool for plant personnel charged with operation and maintenance of the system once designed and installed. The logic diagram as used for final design was found to be directly usable by the operating personnel. Fundamentally, they either knew the process they were trying to run or used the logic diagram as a training tool to determine what should happen. It provided them a road map that they could effectively follow. However, the design information was not enough to serve as a completely effective tool for the maintenance.

By now it is evident that we have been delighted with the results that we have obtained from the use of the logic diagram. The universal communicating tool has provided better design because of involvement of all specialists who could make a significant contribution. The diagrams have graphically displayed the control strategy in terms that everyone can understand and, hence, the surprises at startup have been minimized. With modifications, the basic design tool can be successfully applied and used by the plant to maintain the equipment. This is indeed a powerful tool when the design and operation of equipment must of necessity be delegated to a number of people.

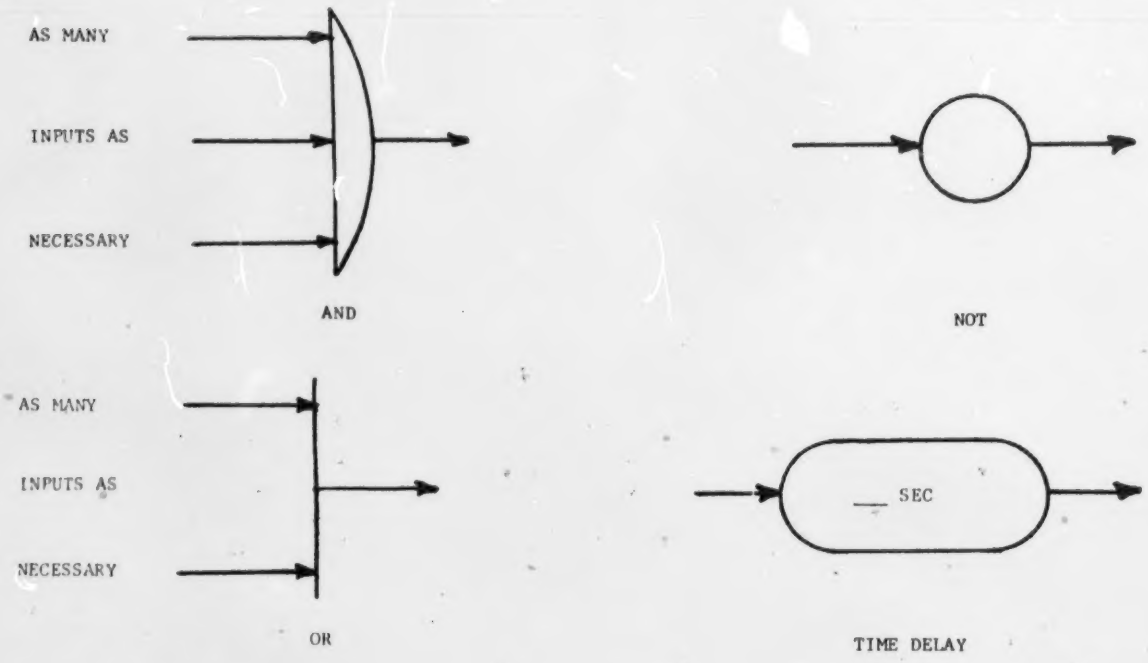
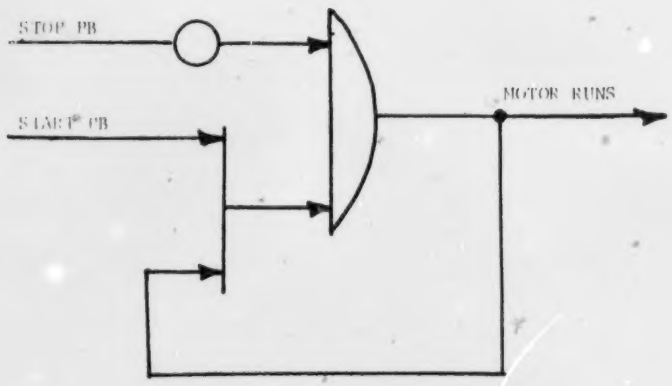
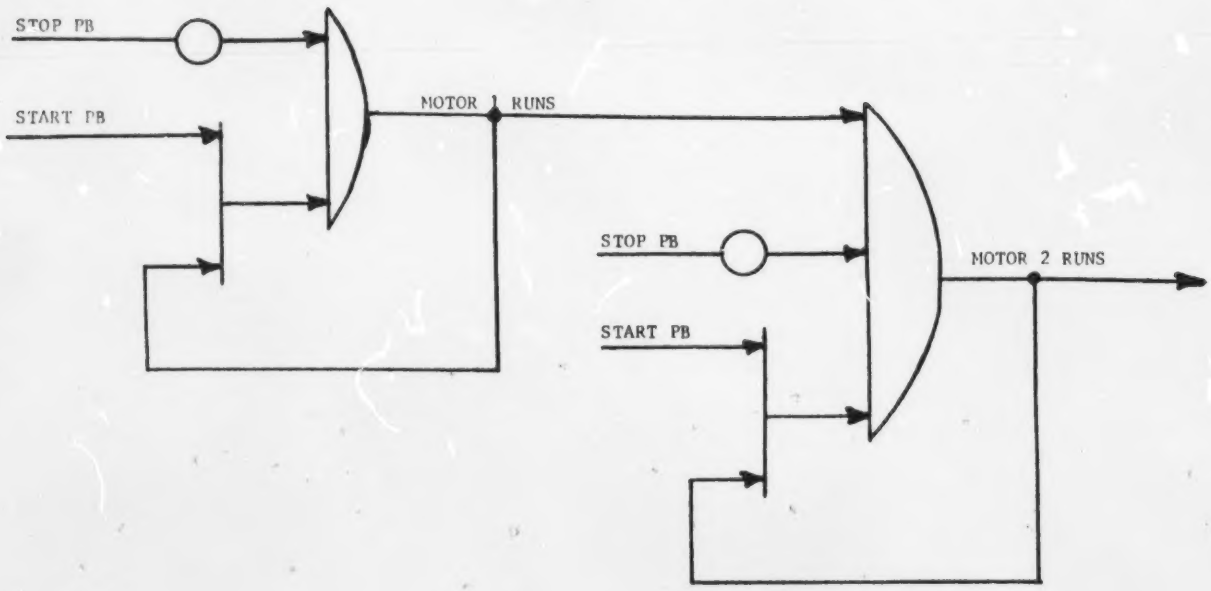


FIGURE 1



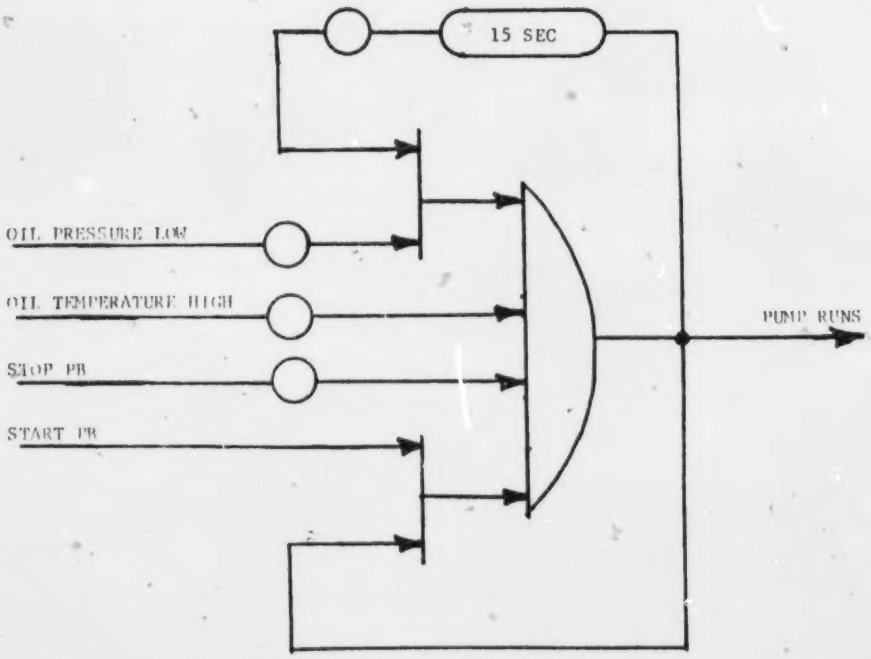
STANDARD MOTOR START STOP CIRCUIT

FIGURE 2



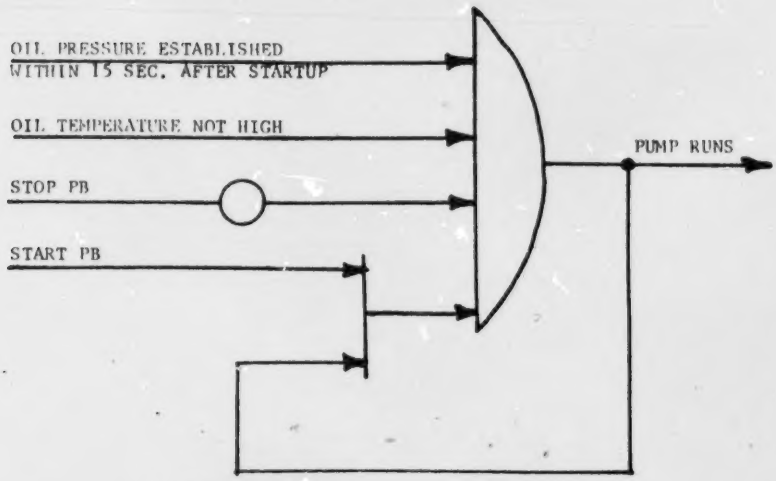
TWO MOTORS INTERLOCKED

FIGURE 3



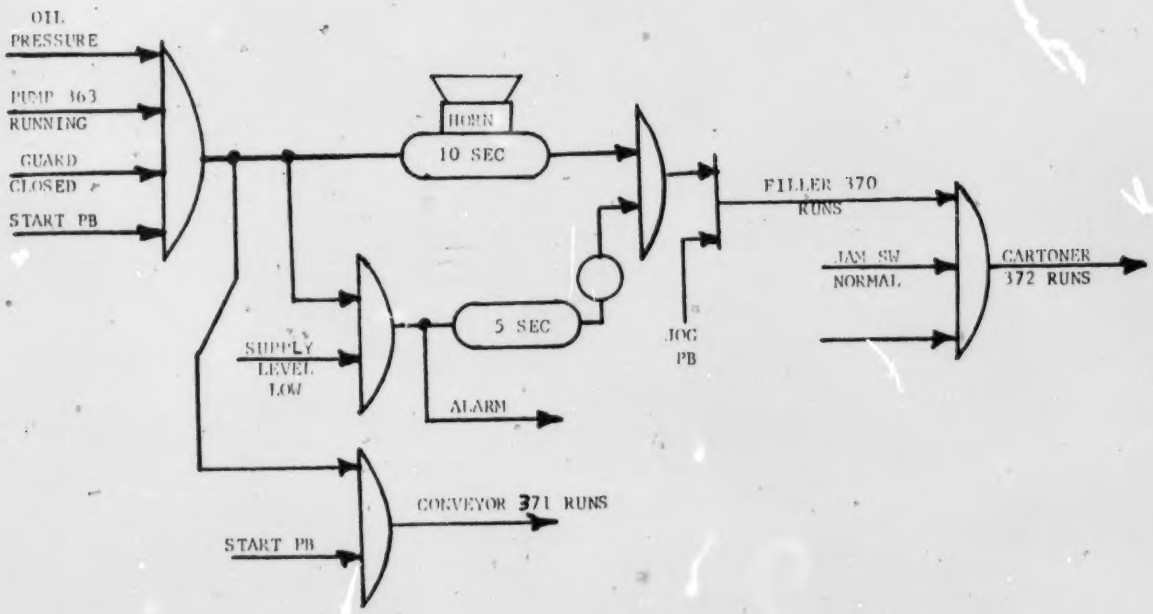
SELF-LUBRICATING PUMP

FIGURE 4



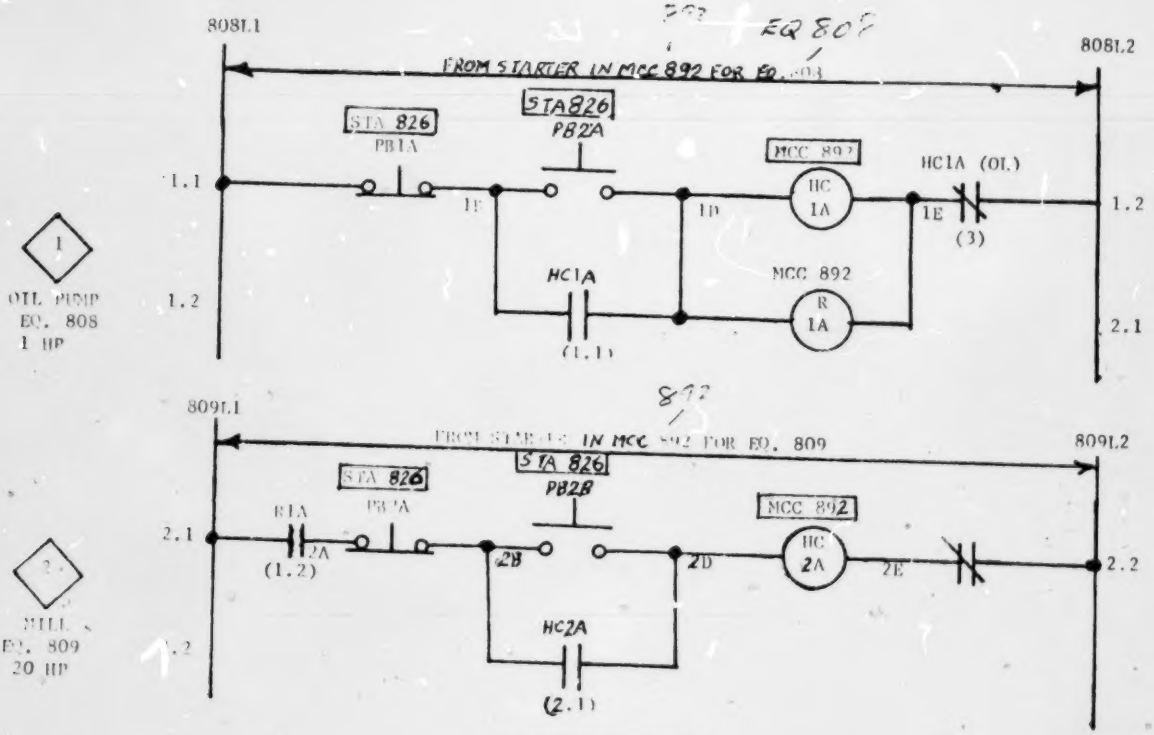
SELF-LUBRICATING PUMP

FIGURE 5



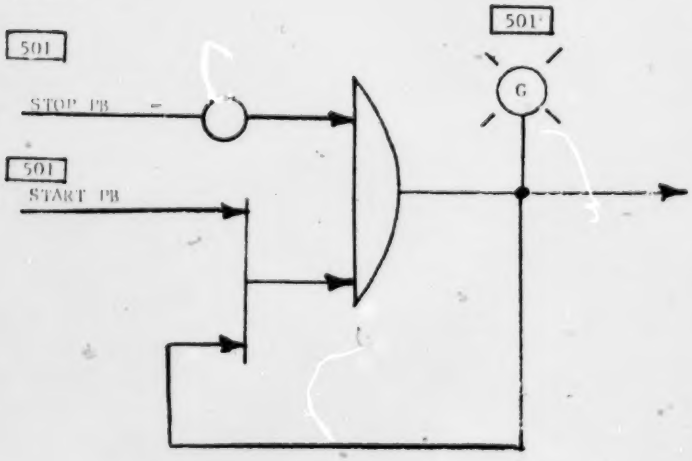
PACKING LINE LOGIC DIAGRAM

FIGURE 6



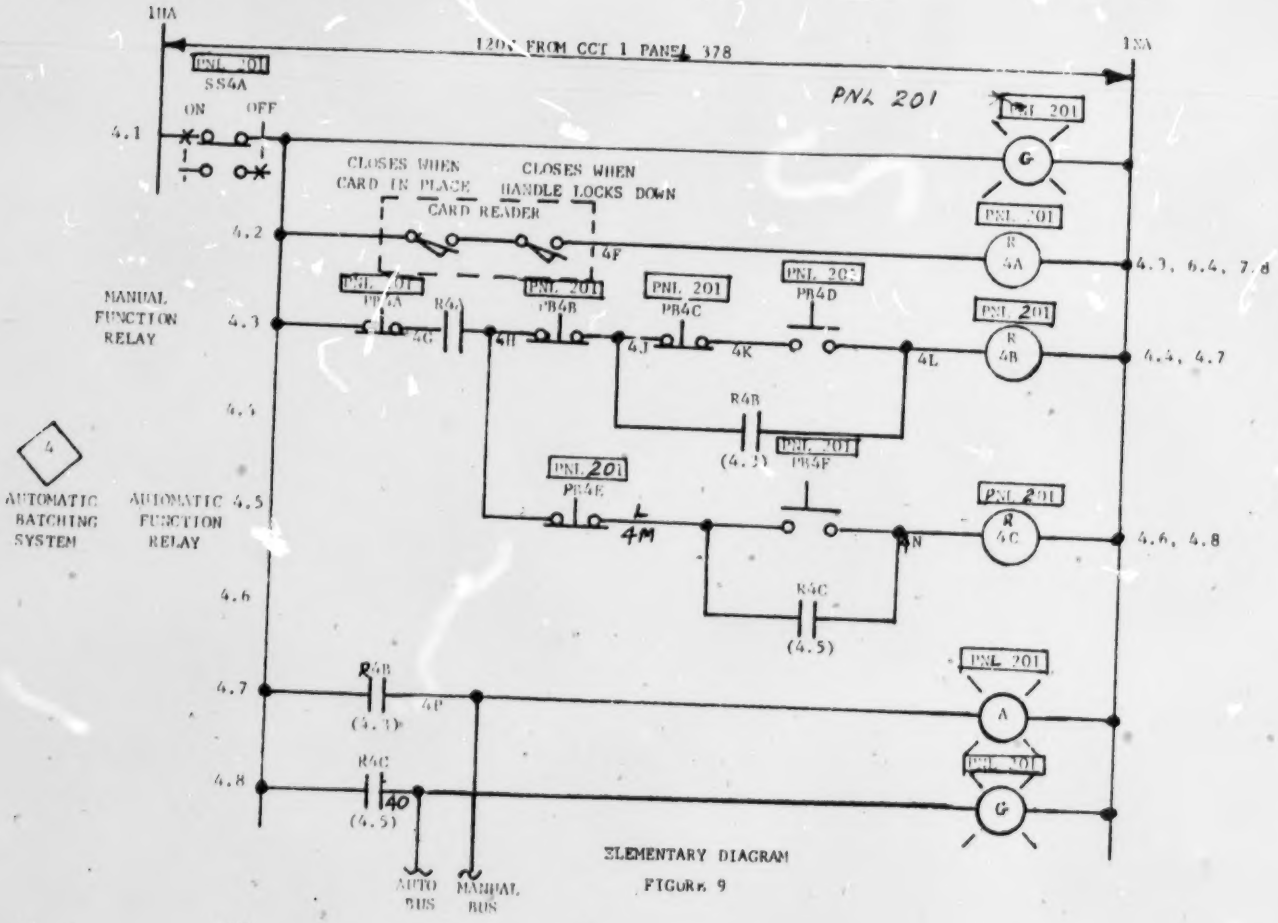
INTERLOCKED MOTORS

FIGURE 7



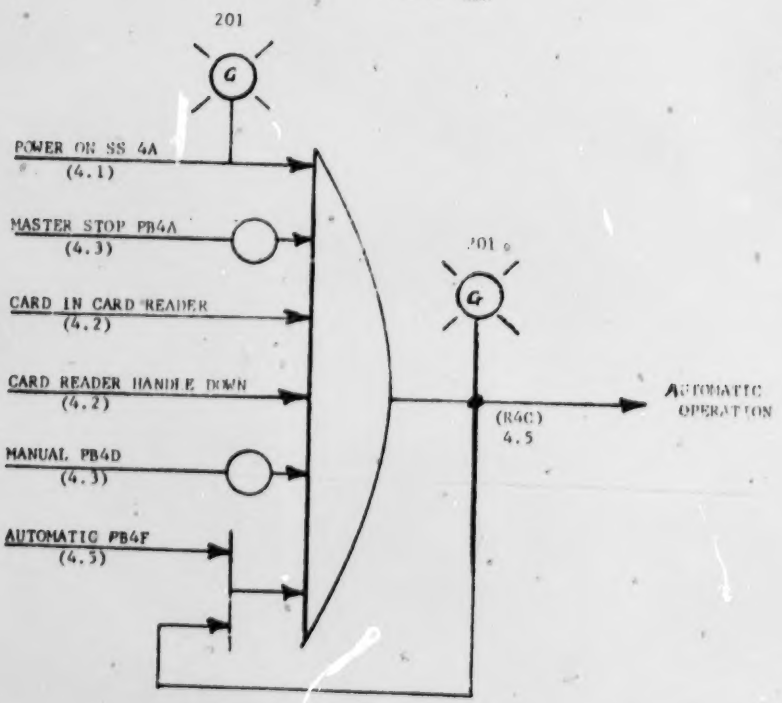
START-STOP CIRCUIT WITH LEGEND ADDED

FIGURE 8



ELEMENTARY DIAGRAM

FIGURE 9



LOGIC DIAGRAM

FIGURE 10

SUBJECT: PUMP OPERATION

TOPIC: 5 VALVES

OBJECTIVES:

The trainee will be able to:

1. Recall the general applications of valves.
2. Name the various types of valves.
3. Name the various components of each valve type.
4. Recall the major function each type of valve performs in the flow system.
5. Describe the operation of each valve.

VALVES

General

Valves are used to start and stop flow, regulate or throttle flow, prevent backflow and regulate pressure. They come in numerous shapes, sizes and components for many applications. This topic will attempt to describe the types of valves most commonly associated with the operation of water and wastewater plants, and what effect valves have on flow systems.

Gate Valve (Figure 5-1)

Gate valves are used for starting and stopping flow. They are usually installed where they are rarely operated, such as in-plant piping systems of both water and sewage plants, pumping stations and water distribution systems. The construction of the valve allows the fluid to move through it in a straight line when valves are fully opened, which in turn produces minimal loss of pressure in the system.

A gate, operated by a stem, screw and handwheel or a key, moves perpendicular to the direction of flow and seats against two valve seats to stop the flow of liquid. The valve can be ordered with a rising stem, also called an outside screw and yoke (O.S.Y.) or a non-rising stem, and can be ordered to open left or right. For unburied services, the former is preferable since one can determine at a glance if the valve is opened or closed. The latter is used when piping configurations limit space and when the valves are buried, such as is the case in a water distribution system.

As a general rule, valves larger than 12 inches should be operated at least once a year. Valves 12 inches and smaller should be operated at least once every 3 years. The operator should never over-tighten the gate valve, as this may damage the seat.

This valve, operated in a fully open or fully closed position, is not recommended for throttling, since a slightly opened gate can cause vibration and erosion with possible damage to the valve.

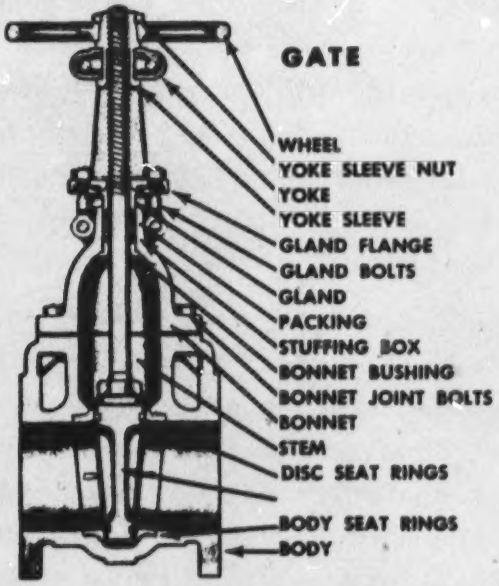


Figure 5-1 Cross-Section of Gate Valve Indicating Various Components by Name

Globe Valve (Figure 5-2)

Globe valves are normally used in smaller size piping for throttling or control of flow. The common feature of these valves is a disc or plug which moves perpendicular to the seat, contacting the seat on closing to provide a tight shut-off. The seats can form part of the body, or can be replaceable.

Because of a high pressure drop through these valves, the "Y" type globe valve was designed. It seats at an angle relative to the valve centerline, resulting in a smaller pressure drop across the valve.

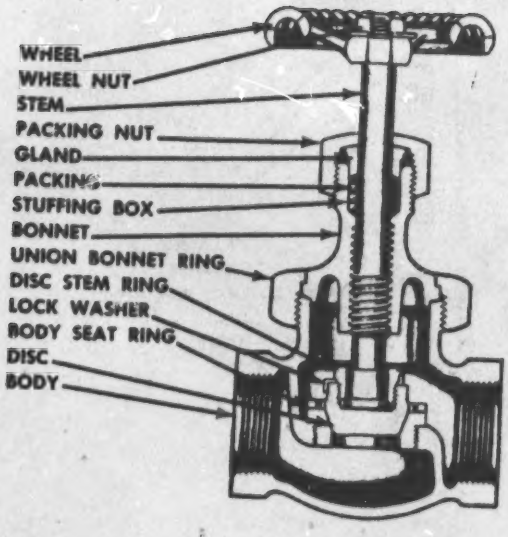


Figure 5-2 Cross-Section of Globe Valve

Angle Valve (Figure 5-3)

The angle valve is an adaptation of the globe valve body. The inlet and outlet connections are at right angles with the stem, in line with one of the connections.

These valves are normally hand-operated and used to accommodate special piping requirements, or to allow drainage of the valve body. This feature is important if the fluid contains sediment which would settle out producing an inoperative valve.

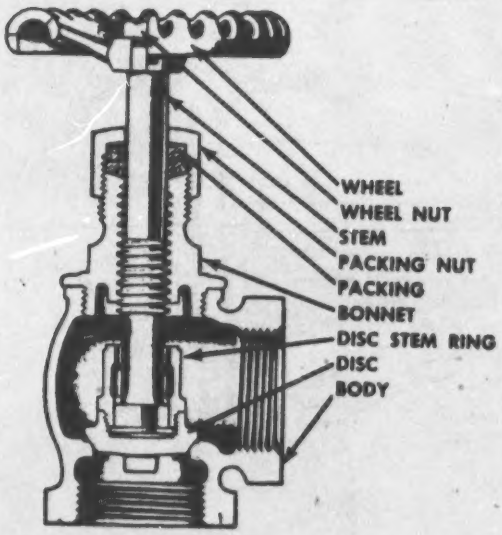


Figure 5-3 Cross-Section of Angle Valve

Butterfly Valve (Figure 5-4)

This valve is normally used under high pressure and high velocity conditions. Because of its straight-through flow pattern, it has the advantages of high capacity and self-cleansing action. This valve consists of a disc (also called a vane or blade), a shaft and a body.

There are two types available; the wafer type and the short pattern flanged-spool type. The wafer body is installed between pipe flanges and, therefore, requires little space. The shaft is a continuous rod supporting the disc. Both shaft and disc thickness are determined by the maximum pressures to be encountered.

The main weakness of this valve is leakage in one direction. This valve is normally found in water treatment plant piping systems and in larger water transmission mains, and can be operated manually, electrically, hydraulically, or pnematically.

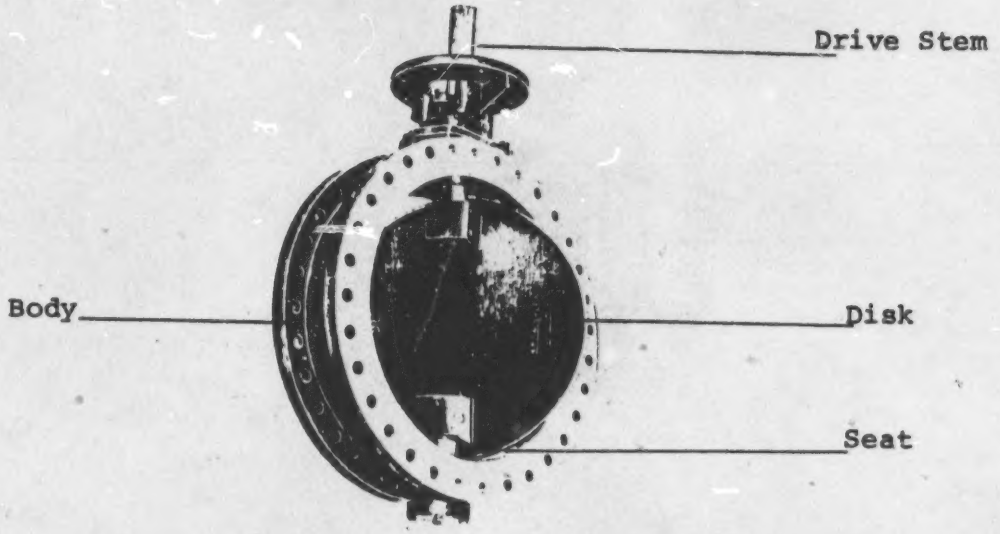


Figure 5-4 Cross-Sectional Diagram of Butterfly Valve

Plug Valve (Figure 5-5)

The plug valve comes in two main types, eccentric and concentric. The concentric valve is lubricated, that is, the face of the plug is lubricated for ease of operation as the plug continually wipes the seat. This unit should be used for gas service.

The eccentric valve has an eccentric plug that pulls away from the seat, therefore, not requiring lubrication. It is used for sludge, raw sewage and scum. A quarter turn moves the valve from fully open to fully closed.

This valve can be provided with multiple ports, that is, three and four way and is used in sewage plant piping arrangements to direct the fluid to various points in the plant.

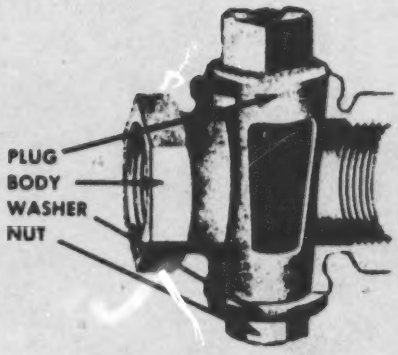


Figure 5-5 Cross-Sectional Diagram of a Plug Valve

Ball Valve (Figure 5-6)

The ball valve has a spherical ball which controls the liquid flow. The best application of this valve is when the fluid velocity exceeds ten feet per second and the fluid pressure is greater than one hundred psi.

The spherical ball has an opening equal to the diameter of the pipe in which it is installed. A quarter turn of the ball closes the valve. Some valves are provided with three or four-way openings. The ball is free floating and sealing is provided by upstream pressure that pushes the ball against a seat ring.

A fire-safe ball valve has a second seating surface formed by a metal lip, which provides a seal if the soft seat is destroyed by external heat. Such valves are used on digester gas lines, seal water line, sewage sample lines, and straight water line.

Applications of the ball valve vary from large watermain installations to digester gas line installations.

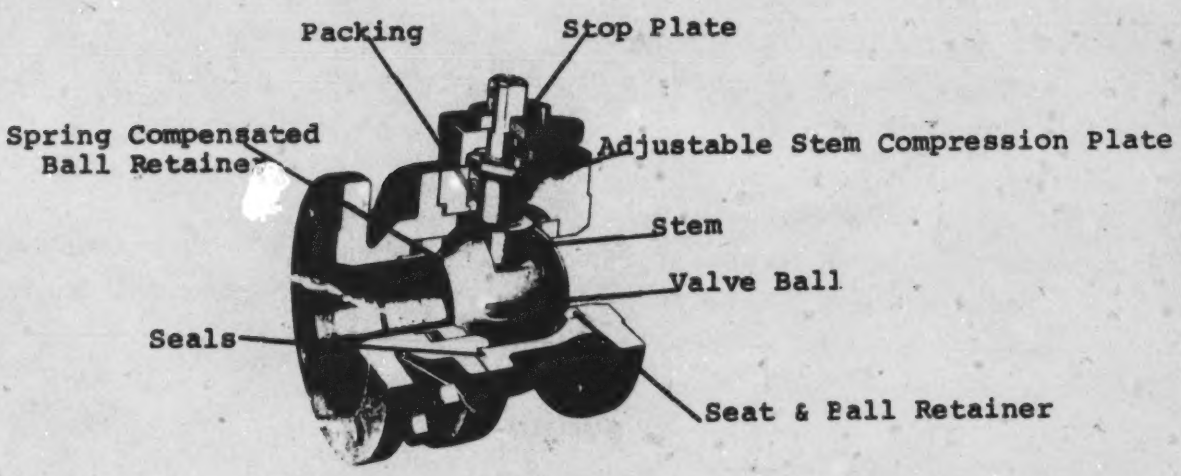


Figure 5-6 Cross-Section of Normal Ball Valve

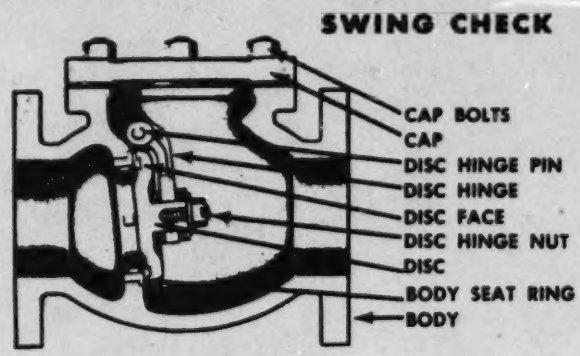
Check Valve (Figure 5-7)

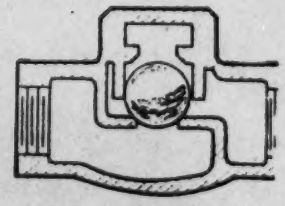
Check valves permit water to flow in one direction only. The swing check valve consists of a hinged disc over a valve port. When there is no flow in the line, the disc is held against a seat by gravity. With flow in the normal direction, the disc swings away from the seat. When flow is reversed, the disc is pushed against the seat and held in place by upstream pressure.

An improvement to this valve is the tilting disc check valve. The disc and seat are at an angle to the line of flow and operate in the same manner as described above. The advantage of this valve is that it is better designed to prevent slamming and water hammer on closing.

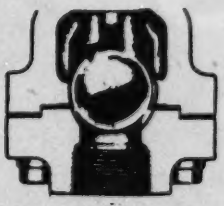
Installation of the check valve is normally on the horizontal plane, however, vertical upflow installations are possible. The check valve is sometimes referred to as a "foot valve" when it is installed for vertical upflow conditions.

A ball check valve is free-floating and sealing is provided by upstream pressure that pushes the ball against the seat ring. Ball check valves are used in chemical feed pumps, and similar applications.





Horizontal Check



Vertical Check

Figure 5-7 Cross-Sectional View Check Valve, Tilting Disc and Ball Check Valve Indicating Various Components

Pressure Relief Valve (Figure 5-8)

A pressure relief valve is installed to protect a system from exceeding its designed pressure. This valve senses a pressure build-up in the system and allows excessive pressure to be dissipated out of the system. The system pressure acts against a spring or weight installed in the valve, pre-set to the required maximum allowable pressure. When the system pressure becomes excessive, the spring or weight "gives" and provides a means of escape for the excessive pressure.

The valve may operate in proportion to the excessive pressure (relief valve), or it may "pop" open as is the case with a safety relief valve.

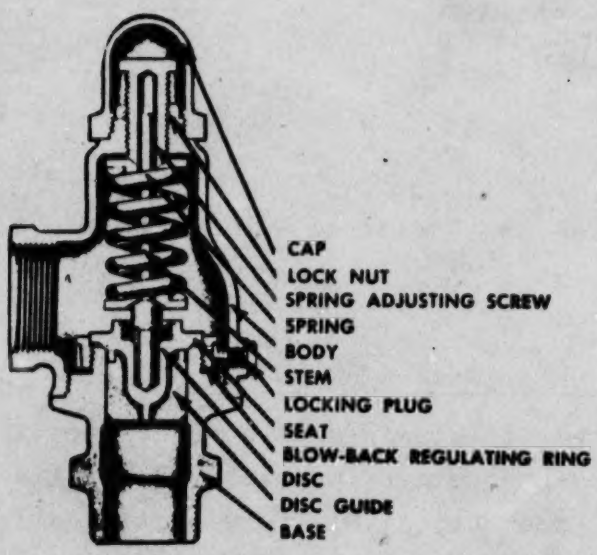


Figure 5-8 Cross-Sectional View of Pressure Relief Valve

Needle Valve (Figure 5-9)

Needle valves provide accurate throttling or control of small flows. The valve has a tapered plug which is allowed to move back and forth within the valve body. The throttling action occurs by positioning the tapered plug to allow a greater or lesser flow through the valve.

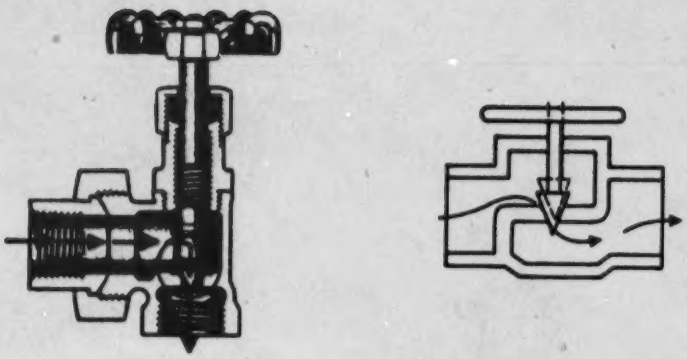


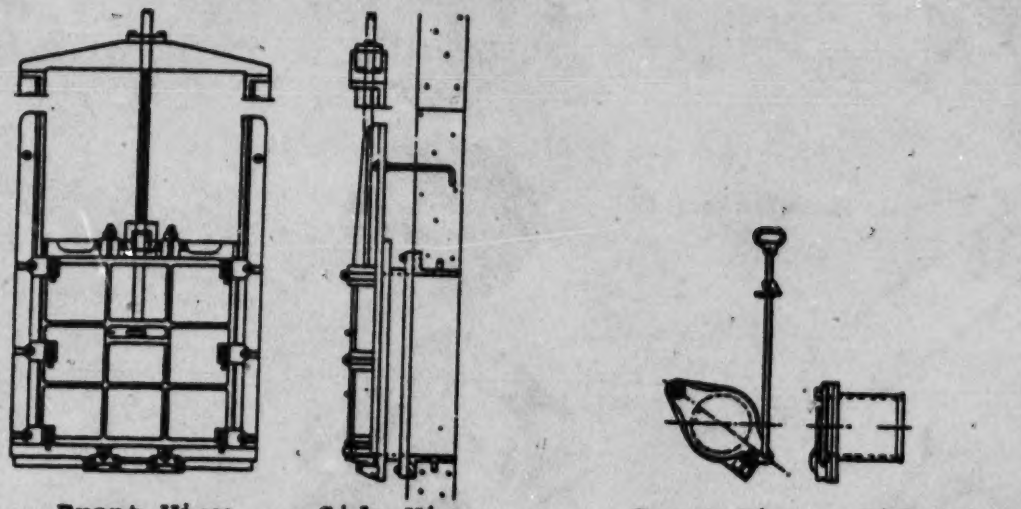
Figure 5-9 Cross-Sectional View of Needle Valve

Sluice Gate and Shear Gate (Figure 5-10)

The sluice gate consists of a metal face installed in guides and can be operated manually, hydraulically, electrically, or pneumatically. Commonly installed at filter bed inlet channels and by-pass lines throughout a sewage plant, these gates are utilized in numerous installations where open channel flows are encountered.

The shear gate consists of a metal disc which seats against a ring and is held in place by liquid pressure. Normally hand-operated, this gate is used for draining tanks.

A common application of the gate is at the effluent chamber of a lagoon.



Front View Side View
Sluice Gate

Front View Side View
Shear Gate

Figure 5-10
Sluice Gate and Shear Gate

Solenoid Valve (Figure 5-11)

The solenoid valve has three basic units; an electro-magnet called the solenoid, a piston or plunger complete with a disc or plug, and a valve. The valve is operated by movement of the magnetically-operated plunger. Two-way, three-way, or four-way valves are available. The two-way valves can be obtained in a closed or opened design. Pilot operators, instrumentation, compressors, humidifiers, air and hydraulic cylinders, are some of the many applications of this valve.

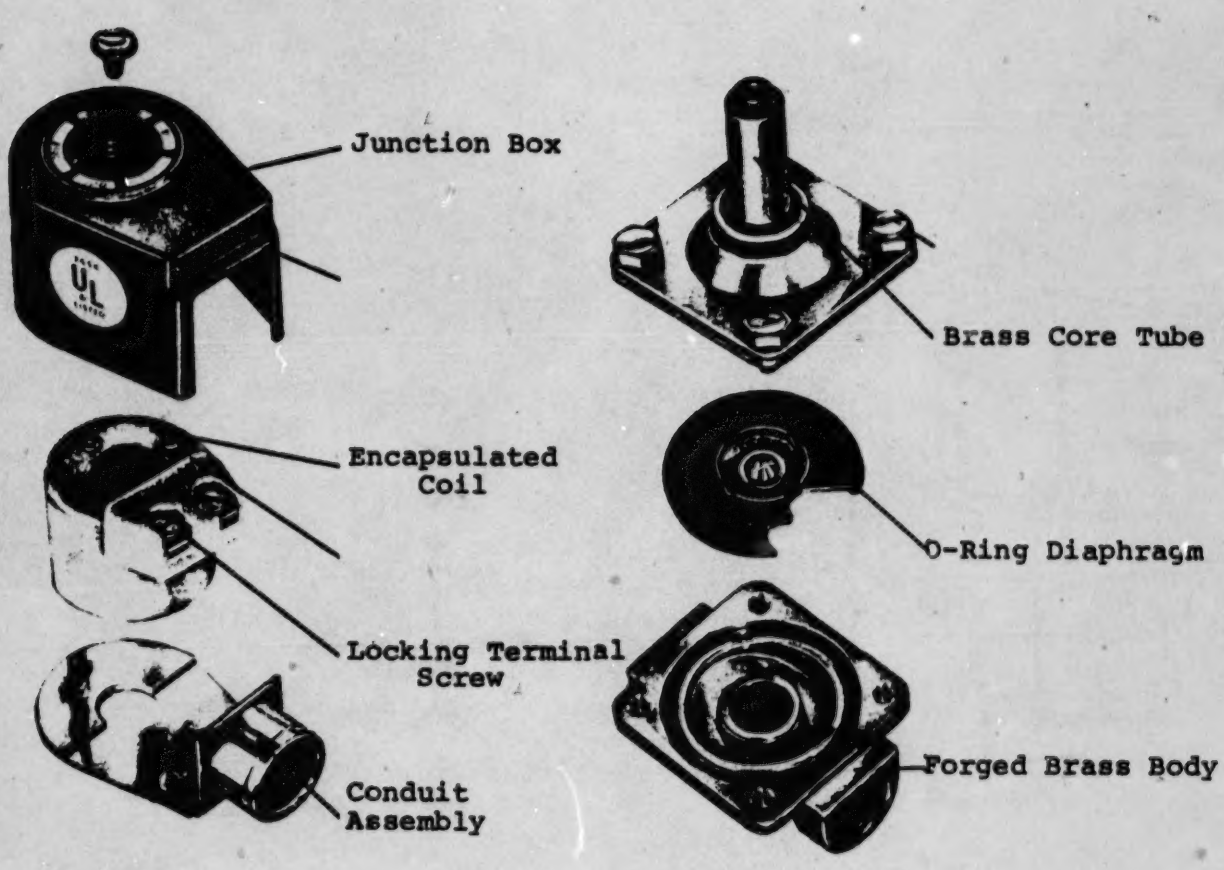


Figure 5-11 Cross-Sectional View of Solenoid Valve

There are various devices that could be supplied with the valve for specific purposes. The above valve descriptions briefly describe the most common types of valves available for water and sewage services. To determine what type of valve to purchase for your requirements, what alternative materials are available for the valve components, and what spare parts should be on the inventory, the plant management should consult their valve suppliers.

SUBJECT:

PUMP OPERATION

TOPIC: 6

MOTORS

OBJECTIVES:

Trainee will be able to:

1. Discuss the factors to be considered when selecting an electric motor as the driving power for a pump.

2. Recall the names and characteristics of various motor enclosures available for different pumping environments.

3. Recall the names and characteristics of two types of AC motors commonly used with pumps.

MOTORS

FACTORS IN MOTOR SELECTION

Pumps are usually driven by electric motors, but may also be driven by internal combustion engines using diesel oil, gasoline, or a liquified gas as the fuel. In some cases, steam turbines, water turbines, or gas turbines may also be used as sources of power to drive pumps. However, the most common driver, at the present time, is the electric motor and it is mainly towards this device that this topic is directed. Electricity is usually the most economical and convenient source of energy. Factors to be considered when selecting an electric motor are:

1. Driving power required by the pump.
2. Speed of rotation of the pump.
3. Environment in which the pump must be operated.
4. Motor types.

Driving Power

The motor must be sized so that the total power consumed by a pumping system is satisfied. The total power is the sum of the power required to:

1. Lift the liquid from its present level to the new level.
2. Overcome friction in the suction line, discharge line, pump intervals, bearings, shaft seals and packing glands.
3. Compensate for the power losses in the drive train between the motor and pump.

Normally, pump drives should be overpowered by about 10%.

In the case of centrifugal pumps, the pump curve should be consulted to ensure that the motor size selected will not cause a motor overload due to a pump "run-out" condition caused when the total head imposed in the pump is decreased. This is illustrated in Figure 6-1. The maximum efficiency determined by the ratio of head capacity to brake horsepower is 70% when the head is 36 feet, the capacity is 6500 gpm,

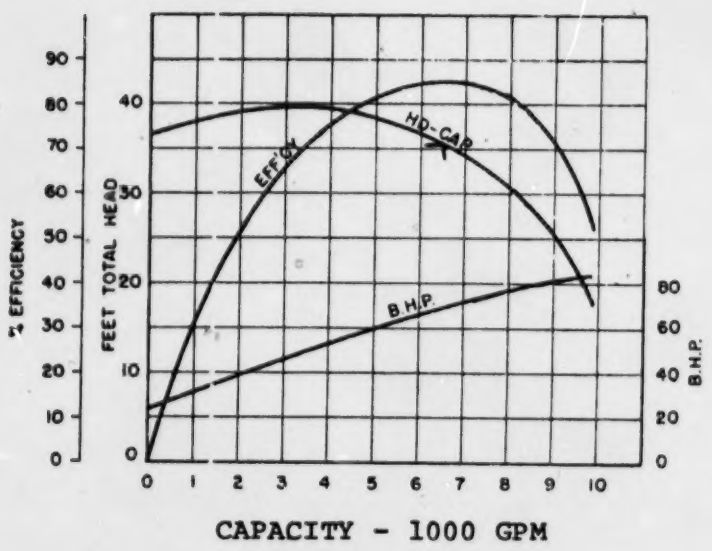


Fig.6-1 Characteristic Pump Curve

and the motor required is 70 HP. However, if the pump is used for anything other than normal duty during which the total head of the system decreases to 30 ft., the pump capacity will increase to about 8,000 gpm and the HP requirement will increase to about 80 HP. Thus, this possibility can be avoided by installing an 80 HP motor at the time of the original installation.

Speed of Rotation of the Pump

Generally, centrifugal pumps have specific speeds of less than 3,000. Thus motor speeds of 3,580 rpm provide the most efficient unit because the specific speed varies directly with the motor speed, and efficiencies increase with increasing specific speed (up to approximately 3,000 rpm specific speed). In addition, the higher the speed of the pump, the smaller and more compact the unit becomes. Accordingly, if efficiency and cost per gallon per minute pumped were the only basis of consideration, the above speeds would be common. However, other factors must be considered such as noise, vibration and suction conditions. When these factors are considered, lower speeds

of rotation are indicated rather than the expenditure which would otherwise be required to correct the problems created by higher more efficient pump speeds.

Thus, for smaller pumps, the more common speed to use is a nominal 1,800 R.P.M. (4 pole motor). For sewage and sludge pumps especially, a nominal 1,200 R.P.M. (6 pole motor) speed is usually used. For large pumps, both for water and waste water pumping, a nominal 900 R.P.M. (8 pole motor speed) is preferred.

Environment

The ideal environment for a pump motor is in clean, dry air - free from dust and dirt, with a low humidity and at an ambient temperature of about 20°C. All of these conditions, are not normally present in one location in water and wastewater treatment plants and pumping stations. However, some of the conditions can be provided at moderate cost at the time the plants and pumping stations are designed. When the environment is less than ideal or when flammable gases may be present, the type of motor enclosure most suited to the conditions prevailing, must be given careful consideration. The specialized types of motor enclosures are more expensive but in the long run can save costly maintenance repairs.

Many motor enclosures are available which will permit operation of an electric motor in a wide variety of environments. The specific application and the nature of any contaminants present will dictate the best enclosure for the job.

Moisture problems require special consideration. Suitable guards or enclosures must be provided to protect exposed current-carrying parts of motors and the insulation of motor leads where dripping or spraying water, oil, or other injurious liquids may occur, unless the motor is specially designed for the existing conditions.

The following are the names and characteristics of motor enclosures available:

1. Open Enclosures

   a) General Purpose. Openings to permit passage of external cooling air over and around the windings of the machine for ventilation.

   b) Drip-Proof. Ventilation openings are so constructed that successful operation is not interfered with when drops of liquid or solid particles strike or enter the enclosure at any angle from 0 to 15 degrees downward from the vertical.

   c) Splash-Proof. Ventilation openings are so constructed that successful operation is not interfered with when drops of liquid or solid particles strike or enter the enclosure at any angle not greater than 100 degrees downward from the vertical.

   d) Guarded. Openings giving direct access to live or rotating parts (except smooth shafts) are limited as to size by the design of the structural parts or by screens, grills, expanded metal, etc., to prevent accidental contact with such parts.

   e) Semi-Guarded. Part of the ventilation openings, usually in top half, are guarded as in a "guarded machine", but others are left open.

   f) Drip-Proof Fully Guarded. A drip-proof machine with ventilation openings as in a "guarded machine".

   g) Externally Ventilated. A machine which is ventilated by means of a separate motor-driven blower mounted on machine enclosure. Mechanical protection may be as defined above.

h) Pipe Ventilated. Openings for admission of ventilating air are so arranged that inlet ducts or pipes can be connected to them.

i) Weather-Protected - Type 1: Ventilation passages are so designed as to minimize the entrance of rain, snow and airborne particles to the electrical parts.

j) Weather-Protected - Type II: Ventilation passages at intake and discharge are so arranged that high-velocity air and airborne particles blown into the machine by storms or high winds can be discharged without entering the internal ventilation passages leading directly to the electrical parts.

2. Encapsulated/Sealed Enclosures

a) Encapsulated Windings. An alternating-current squirrel-cage machine having random windings filled with an insulating resin which also forms a protective coating.

b) Sealed Windings. An alternating-current squirrel-cage machine making use of form-would coils and having an insulation system which, through the use of materials, process, or a combination of materials and processes, results in a sealing of the windings and connections against contaminants.

3. Totally Enclosed

a) Nonventilated. Enclosure prevents free exchange of air between inside and outside of case, but not airtight; not equipped for cooling by external means.

b) Fan-Cooled. Equipped for exterior cooling by means of a fan or fans, integral with machine, but external to the enclosing parts.

c) Fan-Cooled Guarded. All openings, giving direct access to fan, are limited in size by design of structural parts or by screens, grills, expanded metal, etc., to prevent accidental contact with fan.

d) Explosion-Proof. Designed and built to withstand an explosion of gas or vapour within it and to prevent ignition of gas or vapour surrounding machine by sparks, flashes, or explosions which may occur within machine casing.

e) Dust-Ignition-Proof. Designed and built to exclude amounts of dust capable of ignition or amounts affecting performance or rating; to prevent ignition of exterior dust on or in vicinity of enclosure.

f) Waterproof. Designed to exclude water applied in a stream from a hose. Leakage is permitted around the shaft provided that water is excluded from oil reservoir and means of drainage is provided.

g) Pipe-Ventilated. Openings so arranged that inlet and outlet ducts or pipes may be connected to them for the admission and discharge of ventilating air.

h) Water-Cooled. Cooled by circulating water; the water or water conductors come in direct contact with the machine parts.

i) Water-Air-Cooled. Cooled by circulating air which, in turn, is cooled by circulating water.

j) Air-To-Air-Cooled. Cooled by circulating internal air through heat exchanger which, in turn, is cooled by circulating external air.

MOTOR TYPES

Alternating-current (AC) motors are the type most often used, although in some cases direct-current (DC) motors may be used, but they are very much less common.

Synchronous and induction motors are the most readily available types of AC motors. In the smaller sizes, the induction type motor is most frequently used.

Synchronous Motors

These operate at a constant speed under widely varying load conditions. The designed motor speed is a function only of the frequency of the power supply. Synchronous motors are equipped with a DC generator that supplies the rotor current. The DC generator is driven either by the synchronous motor itself or by a small auxiliary AC motor. The stator uses AC power to produce the required magnetic field. This is synchronized with the DC magnetic field in the rotor, hence the term "synchronous" motor.

The efficiencies of synchronous motors are high, falling between 92 and 97%. These motors require complex rotor windings and control devices for the rotor's DC field. The expense of the auxiliary equipment precludes the use of this type of motor below 250 H.P. While operating speeds range between 300 and 3,600 rpm, the most common speeds are 900 and 1,200 rpm.

Synchronous motors operate usually at unity power factor, but may be operated at slightly lagging or leading power factor depending on the electrical system at the plant or pumping station.

Induction Motors

In these motors, AC power in the stator is used to induce a current in the rotor. Induction motors are available in two types: wound rotor and squirrel-cage rotor. In the former, the rotor is wound with wires that cut the magnetic field of the stator when the armature is rotated. This action induces a current and magnetic field in the rotor.

The squirrel-cage rotor is not wound with wires but consists of numerous parallel bars. Squirrel-cage motors provide a relatively constant speed, but the variation in speed is substantially greater than with synchronous motors. They are the simplest and usually the least expensive of the types discussed. Efficiency is about 3% less than for comparable synchronous motors. Squirrel-cage induction motors are available in sizes from fractional to 10,000 H.P. but operate best in the 600 to 3,600 rpm range. However, above 500 H.P., synchronous motors with their higher efficiency may be more economical.

Wound rotor motors may be used as variable speed motors using a resistor bank and drum switch or electronic controller connected to the secondary windings. By varying the external resistances various speeds may be obtained. This procedure allows large motors or motors having a high starting torque requirement to start up with a high resistance in the secondary which will deliver a high-starting torque at low speed and by reducing this external resistance gradually produce accelerating torques which draw comparatively little current from the line. For operation, it is usually not recommended to operate at less than 50% of full speed on a continuous basis.

Squirrel-cage motors may be of the multispeed type by using the two-winding type. In this case there are two separate stator windings so that any two nearly synchronous speeds can be obtained by switching from one winding to the other.

Preventive Maintenance

With good preventative maintenance practices, electric motors have a long life. To prevent the burnout of motor windings it is common to provide protection for a motor overload. Overloading of a motor shows up in two ways: excessive amperage drawn and excessive temperature rise in the motor caused by the heat produced by the high current drawn and the resistance of the motor wirings. Thus to protect the motor from an overload, one or both these effects can be sensed and a relay activated to provide an alarm or shut down the motor. Overcurrent relays are usually provided in the starting circuit of a motor to shut down the motor when excessive current is drawn. In addition, thermal detection devices may be embedded in the motor windings which will detect temperature. These devices may be used to provide an alarm when a certain preselected temperature is reached and to shut down the motor when a higher pre-selected temperature is reached.

A planned and regular maintenance programme can very easily prevent motor failures. The following items should be included in any such programme:

1. Dirt, dust, grime - plugs ventilating spaces and prevents cooling by providing an insulating layer over the metal surfaces intended to radiate heat.

   Exterior surfaces may be wiped off with a clean cloth; waste fibres are not recommended as they may become caught on sharp corners and motor openings on some types of enclosures.

Dry air at a pressure not over 50 psi may be used to blow dust out of motor windings. A petroleum distillate with a flash point of over 100°F, specially formulated to remove grease and oil films may be pressure sprayed over the motor and its internal windings. Non-toxic type fluids should be used, but in all cases, the ventilation recommendations of the manufacturer should be strictly followed.

2. Moisture - harms insulation on windings so they no longer can provide the required insulation for the voltage applied to the motor. In addition, moisture on windings tends to absorb acid and alkali fumes and thus become very destructive agents for insulation and metals.

   To combat moisture the most suitable enclosure for the existing environment should be used, or in some cases, a dehumidifying system may be warranted. In addition to these capital expenditures, standby motors should be run at regular intervals to dry up any condensation which may have occurred.

3. Friction - causes wear in all moving parts. Lubricants are used to reduce friction between moving surfaces and manufacturers lubricating instructions should be followed very strictly.

   Excessive oil or grease should not be used as this will cause friction itself.

   Do not add new oil while a motor is running.

4. Vibration - causes parts to shake loose; may break electrical connections; may crystallize parts of the metallic structures.

   Where excessive vibration is experienced, look for the cause. It may be due to misalignment between the motor and the pump in excess of that compensated for by the pump coupling. It may be caused by the pump and transmitted through the

pump base or shaft to the motor. It may also be caused by a bent motor shaft, loose bearings, or loose mounting bolts.

During the inspection of motor windings, they should be checked to ensure they are snug in their slots and the insulation should be fresh, flexible, and treated with varnish or epoxy. As the insulation dries due to age, it loses its flexibility, and vibration may cause short circuits in the coils and possible failure from coil to ground, usually at the point where the coil leaves the slot. Properly applied varnish and baking treatments will fill all air spaces caused by drying and shrinkage of the insulation will maintain a solid winding and will provide an effective seal against moisture.

SUBJECT: PUMP OPERATION

TOPIC: 7 SAFETY

OBJECTIVES:

The trainee will be able to:

1. Name the levels of authority responsible for maintenance of safe working conditions.

2. List the (personal) hazards common to water and wastewater operations.

3. Recall the safety rules to follow when working around:

   (a) pumps
   (b) chemical feeders
   (c) lines under pressure
   (d) rotating shafts, pulleys, etc.
   (e) motors.

4. Recall the general rules that should be followed regarding personal apparel.

5. Recall the safety practices to be followed in use of hand tools.

SAFETY IN PUMPING OPERATIONS

INTRODUCTION

Whether one is engaged in a waterworks system or in a wastewater treatment operations, accidents do not just happen, rather they are caused. This topic is intended to provide the operators with a background in the areas that are of special concern regarding pumping operations.

RESPONSIBILITY

Everyone is responsible for the maintenance of safe working conditions. This includes the:

1) Employer
2) Job Supervisors
3) Individual on the Job

The employer is responsible for maintaining both safe working conditions and supporting a policy that encourages safe performance of work duties.

Supervisors are responsible for direct control of work conditions. This means that each crew chief has a responsibility to see that all work is done in compliance with safety practices and regulations.

The employee has a special responsibility in regard to safety. He must practice safety procedures and make use of all safety equipment necessary for the specific tasks, otherwise the safety program will not be successful.

HAZARDS

The two major hazards to which an individual working with pumping systems is exposed are:

1. Physical Injuries
2. Body Infections

Physical injuries may result from high-speed rotating shafts, couplings, idlers, or in certain installations rotating wheels; also serious injury may be sustained by exposure or contact with electrical currents which supply power to the driving units or the motors of the pumps. It should be recognized that there are many other hazards in close proximity of pump operations such as slippery floors as a result of oil or other materials, injuries resulting from heavy lifting or those caused by falls. Always lift with the leg muscles instead of the back and be sure your footing is secure. Bend your knees and keep your back straight. Don't turn or twist your body when lifting. Get help if load is too heavy or awkward to handle. Use mechanical device for lifting wherever possible.

In pumping operations another very serious hazard which should not be overlooked is the fact that all pipes on the discharge side of the pumps are operating under pressure. An unguarded, sudden opening of a drain valve or a tap may result in a jet of water, or other material pumped, hitting the unsuspected individual in the face or another part of his body. The released material may contain a hazardous chemical, it may be hot, or may contain infectious organisms.

PERSONAL APPAREL AND WORKING CONDITIONS

A good general rule is to dress to fit the particular working condition. The tendency of loose or ill-fitting clothing is to catch on objects or be caught up in the machinery, constitutes a serious danger to the worker. Trouser cuffs, particularly on broad sloppy pants, have frequently caused tripping and falling. Missing buttons, rips and tears should be repaired immediately. Dirty or

soiled clothes with oil, chemicals or other flammable material can be a great safety hazard. When clothing is soaked with flammables, a spark can turn a wearer into a human torch. Even when they do not ignite, many chemicals have caustic properties that will cause all kinds of skin irritations, and even poison the system in contact with liquid or vapor.

Jewellery

Rings, bracelets, and necklaces all create projections and catch in machinery with mutilating results. Long unconfined hair is another hazard to a worker around moving machinery. Therefore, tight fitting clothing is the rule when one is working with or around machines, or handling bulky materials. A sleeve caught on a frayed wire of a winch-drum could attach a man to a winding cable, or a rotating shaft. Rings on fingers could turn what would have been a minor abrasion into a deep cut or a lost finger.

Contaminated clothing may be harmful to the wearer as well as his co-workers. Chemicals used in treatment process, sprayed sewage, acid and caustics, gasoline and other flammable materials are all examples of dangerous contaminants.

Gloves

There is a wide variety of gloves for various jobs. The worker should select the right type of glove for the particular job. Although gloves will not totally prevent injury in a particular accident, they will minimize it. Gloves are indispensable in handling heated objects, caustic materials, or other rough materials such as broken concrete or lumber. However, the worker should never wear gloves when handling moving machinery. *They are easily caught in gears or moving parts and if this happens the gloves will not be of much help.*

Safety Shoes

Personnel engaged in water treatment and wastewater treatment operations should wear recognized and approved safety shoes. There are three ways in which the feet could be injured;

1. Being crushed by weights.
2. Being cut or wedged in apertures.
3. Stepping on rusty nails or other sharp objects.

Eye Protection

An operator should remember that wherever he is required to wear gloves to do his job, it is probably necessary to wear protective eye glasses. Caustic chemicals or other dangerous products, which cause irritation to the skin, will likely also cause damage to the eyes. It is important to protect the eyes when working in areas which are susceptable to spray or splash of liquids.

HAND TOOLS AND SAFETY PRACTICE

Accidents when using hand tools account for a high percentage of disabling injuries. This type of accident is most likely to happen when a tool is in poor condition or is used improperly, or in an unsafe manner. The following are some simple suggestions for safe use of hand tools:

1. Select the right tool for the job.
2. Use only tools in good conditions.
3. Cutting or drilling tools should be kept sharp and stored in safe places.
4. Use wrenches of the right size for the job and never apply a wrench to machinery in motion.

MACHINE GUARDS

1. Safety guards, over rotating couplings, shafts or fly-wheels, etc. should not be removed while equipment is in operation. They should be kept in good repair and securily fastened.

2. Equipment which requires frequent addition of lubricants, the safety guard should be equipped with openings provided with self-closing covers.

3. In certain installations, where manual lubrication is required frequently while the equipment is in operation, extensions should be installed on the lubricating fittings to eliminate the necessity of lifting the safety guard.

EQUIPMENT SERVICING

When servicing plant and equipment, **DO NOT:**

1. Grease or oil or attempt to service any machinery while it is in operation. Pumps on automatic control must be locked out and key carried by the operator during servicing.
2. Make any adjustments to operating machinery while alone. If it is necessary to run the unit to adjust it, a second man must be present and be beside the stop and go switch.
3. Work around electrical panels, disconnects or switches alone.
4. Enter any crawl space under flooring for any purpose until the area has been ventilated. A second man should be present.
5. Service pumps and shafts in the dry wells of pumping stations, and in plants where the pumps and shafts are less than three feet apart, without shutting off all pumps and locking them out.

6. Under any circumstances, attempt to grease or service pump shafting while standing on beams, piping, loose planks, guard rails, or by leaning out, over or through guard rails. If a ladder must be used, then a second man must be present to hold the ladder steady and to provide any other assistance.

PRECAUTIONS FOR ELECTRICAL MAINTENANCE

1. Plan safety into each job. Orderliness and good housekeeping are essential for your safety and the safety of others.
2. Each employee shall be qualified both in experience and general knowledge to perform the particular electrical work which he is assigned. Outside contractor to be called in.
3. Study the job carefully to determine all of the hazards present and to see that all necessary safeguards and safety devices are provided for safe working conditions.
4. Examine all safety devices before they are used to ensure that they are in good condition.
5. In all cases where work is being performed on or close to live conductors or equipment, at least two men shall work together. When it is necessary for one to leave, the other workman shall not continue the work until the first man returns.
6. Consider the results of each action. There is no reason for you to take chances that will endanger yourself and others.
7. Satisfy yourself you are working under safe conditions. The care exercised by others can not be relied upon.

8. Wear close fitting clothing, keep sleeves rolled down, avoid wearing unnecessary articles while working on or close to live circuits or apparatus.

9. Use only approved types of rubber or leather gloves.

10. Protect yourself by placing an insulated medium between you and ground or grounded apparatus to keep any part of your body from providing a path for electrical current when working on conductors or apparatus that may be energized.

11. Use rubber mats when working on any electrical control panel or switch and disconnect boxes.

12. Open and close switches completely with a firm positive motion. Switches in a partly open position may arc or cause a flash-over with damaging results to the switch and possible injuries to the operator.

13. Open switches fully before removing fuses. To remove a fuse from a circuit carrying a current without opening the switch is particularly hazardous. Use an approved low-voltage fuse puller to remove fuses on a circuit of less than 500 volts (where no switch is provided) whether a disconnect is provided or not. Remove fuses by breaking contact with the hot side of the circuit first. Use the reverse procedure when replacing fuses. Insert the fuse in the cold terminal first.

14. Do not stand directly in front of panel to remove fuses or shut off disconnects.

15. Shut off the power when examining or making repairs or alterations on light and power circuits. When this is impractical Head Office must be contacted for further instructions before proceeding with the work.

16. Consider all electrical circuits to be dangerous. Treat dead circuits as though they were alive. This may prevent an accident as the circuit may be closed through an error of some other person.

17. Exercise extreme care when required to locate troubles on a series lamp circuit, before repairs are made make sure the power is cut off.

18. Lock or block open the control devices, open disconnect switches or remove fuses before examining, repairing or working on power circuits. After these precautions have been taken, attach tie-up tags worded "WORKMEN ARE WORKING ON LINE." The tag shall bear the name of the workman. Tie-up tags shall remain on the opened devices until removed by the workman whose name appears on the tag. If the workman leaves without removing his tag, it may be removed only on authorization of Head Office.

19. Before working on line circuits at a point remote from the control switch, which has been tagged, it is recommended that the conductors be grounded at a point on the line between the switch and the work station.

20. Make a complete check of the circuit before applying power for the first time. This is to be done by a qualified man in charge of the repairs, all other workmen to stand off at a safe distance.

SAFETY IN CHEMICAL PUMPING

The characteristics of chemicals pumped will particularly affect the safety precautions to be taken in pump operation and maintenance. The following list indicates the hazardous aspects of some of the chemicals commonly used in pumping systems for water supply and/or water pollution control operations:

CHEMCIALS	POSSIBLE EFFECTS
Liquid Alum	- irritates skin
Ferric Chloride	- stains - corrosive - irritates eyes, nose, lungs, skin
Ferrous sulphate	- irritates eyes, nose, lungs, skin
Lime Slurry	- powder is irritating during mixing
Fluosilicic Acid	- very corrosive - harmful to skim, eyes
Hydrogen Peroxide	- can cause severe burns to eyes, skin
Potassium Permanganate Solution	- avoid contact with eyes, skin - avoid breathing dust when preparing solution - fire hazard
Sodium Fluoride Solution	- dust, vapour harmful - toxic
Sodium Chlorite	- avoid contacting it with cellulose material as it is explosive when in contact with organic matter - store in clean, cool, dry area

CHEMICALS	POSSIBLE EFFECTS
Sodium Silicate	- viscous solution
Sodium Hypochlorite	- irritates eyes, skin - corrosive - protect from light - store in cool place - bleaches out colours from clothing

It is obvious from glancing at this brief list that proper protective clothing (usually eye protection, rubber gloves and apron) must be worn when working around some of these chemical pumping systems. Other safety considerations of pump operation will be discussed in a later Topic.

Use safety equipment as it was meant to be used. This should be compulsory during the performance of hazardous jobs.

Protect eyes and face when there is any possibility of injuries from hand tools, power tools, welding equipment, etc.

Protect feet with safety shoes to safeguard against injuries while breaking pavements, tamping trenches, handling materials, etc.

Protect head (with hard hats) to prevent serious injuries in construction, excavation or electrical work.

Protect hands (with gloves) to prevent injuries from occurring when handling materials, sharp objects, chemicals or electrical equipment.

SUBJECT:

PUMP OPERATION

TOPIC: 8

Practical Applications and Troubleshooting

OBJECTIVES:

Given demonstrations and hands-on practice, the trainee will understand and be capable of performing the following functions;

1. Prime pump by each of the following methods:
   a) Vacuum-Suction lift with or without foot valve.
   b) Forced prime (flooding) - suction lift with foot valve.
   c) Venting pump casing - suction head.
2. Cause cavitation on a loss of prime by applying:
   a) Excessive suction lift.
   b) Insufficient suction head.
   c) Entrained air in pump.
3. Quieten cavitation noise by injecting air into pump entrance.
4. Overload pump motor by reducing the system head.
5. Measure and compare total head on pump when employing each of the four discharge lines:
   a) Open loop to discharge tank.
   b) Submerged entrance to discharge tank.
   c) Open loop to suction head tank - by-pass discharge tank.
   d) Open loop to suction head tank - short discharge line.

OBJECTIVES: (cont.)

6. Measure and compare loss of head across each of the following:
   a) 1½ x 90° elbow
   b) 1½ tee line
   c) 1½ tee branch
   d) 1½ gate valve
   e) 1½ swing check valve
   f) 1½ globe valve
   g) 1½ flow meter by-pass
   h) 1½ flow meter
7. Evaluate the effect of liquid temperature on pump performance.

GLOSSARY

brake horsepower -
The actual horsepower of the drive required to produce a given water H.P.

dynamic discharge head -
Is the vertical distance in feet between the pump centre line and point of free discharge or to the level of the free surface of the discharge water, plus velocity head and friction losses in the discharge piping

dynamic suction head -
Includes static suction head minus the sum of friction head loss and velocity head.

dynamic suction lift -
Includes the sum of static suction lift, friction head loss, and velocity head.

efficiency of a pump -
The ratio of the output (water horsepower) to the input (brake horsepower).

energy -
The capacity to perform work. It is expressed in units that are the product of weight and length. The unit of energy is the product of a unit weight by a unit length, i.e. the foot-pound, which is the energy required to move one pound one foot.

Energy exists in two forms:

1. Potential Energy - that due to position or elevation.

2. Kinetic Energy - that due to its velocity of motion.

friction head -
The pressure expressed in lbs./sq.in. or feet of liquid needed to overcome the resistance to the flow in the pipe and fittings.

liquid horsepower (water horsepower) -
This is the theoretical horsepower required to pump water at a given rate against a given head, and is obtained from the formula:

$$\text{water h.p.} = \frac{\text{U.S.G.P.M. x head in feet x specific gravity}}{3960}$$

or

$$= \frac{\text{I.G.P.M. x head in feet x specific gravity}}{3300}$$

The constance 3960 is derived by dividing the number of foot pounds of one H.P. (33,000) by the weight of one U.S. gallon of water (8.33 lbs.).

power -
The rate of performing work, and is expressed in horsepower, 550 ft-lb/sec, or kilowats, 737 ft-lb/sec.

rating (or rated capacity) -
This describes the condition for which the pump is designed. A pump is said to be rated at a given capacity for a given head. This condition generally occurs at the point of maximum efficiency.

specific gravity -
Direct ratio of any liquid's weight to the weight of water at 62°F. Water 62°F weighs 8.33# per gallon and is designated 1.0 sp. gr.

specific speed -
A speed or velocity of revolution, expressed in revolutions per minute, at which a pump of suitable size and proportion, would develop one-foot of head if powered by one horse-power motor used for pump design.

static discharge head -
The vertical elevation from the centre line of the pump to the point of free discharge.

suction head -
Exists when the source of supply is above the centre line of the pump.

suction lift -
Exists when the source of supply is below the centre line of the pump.

static suction head -
The vertical distance from the centre line of the pump up to the free level of the liquid source.

static suction lift -
The vertical distance from the centre line of the pump down to the free level of the liquid source.

total dynamic head -
The vertical distance in feet from the free liquid level to be pumped, and point of free discharge, or to the level of the free surface of the discharge, plus velocity head and friction losses in the suction and discharge piping.

velocity head -
The head needed to accelerate the liquid. Knowing the velocity of the liquid, the velocity head loss can be calculated by a simple formula $\text{Head} = V^2/2g$ in which g is acceleration due to gravity or 32.16 ft/sec.^{2}.

viscosity -
Property of a liquid that resists any force tending to produce flow. It is the evidence of cohesion between the particles of a fluid which causes a liquid to offer resistance analogous to friction. A change in the temperature may change the viscosity depending upon the liquid. Pipe friction loss increases as viscosity increases.

power -
The rate of performing work, and is expressed in horsepower, 550 ft-lb.sec, or kilowats, 737 ft-lb/sec.